EVALUATION OF AQUATIC VEGETATION MANAGEMENT TECHNIQUES IN STORMWATER RETENTION BASINS

BY

DAVID A. WARDROP, P.Eng.

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

Department of Civil and Geological Engineering
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ABSTRACT

The City of Winnipeg Water and Waste Department presently operates and maintains 70 Stormwater Retention Basins (SRB's) within its boundaries. Developers' promotion and marketing of SRB's as pristine water bodies as opposed to naturalizing wetlands or drainage structures has resulted in a perception and service expectation by residents which is difficult, if not impossible to satisfy. In response to these expectations, approximately one third of these basins are mechanically harvested for the removal of aquatic weeds each summer. Limitations on the number of harvestable basins exist due to time, availability of equipment, site conditions at some stormwater retention basins, and budget.

These problems, in addition to the rapid proliferation of weed and algae concentrations observed subsequent to harvesting, resulted in questions with respect to the impact mechanical harvesting has upon chlorophyll a concentrations in SRB's. Water quality analysis indicated that subsequent to harvesting activities, no reduction in chlorophyll a concentration was observed in any of the test basins, despite the removal of aquatic vegetation during harvesting. Chlorophyll a concentrations actually increased substantially in five of the six test basins immediately following harvesting operations, and remained unchanged in the sixth. The increases in the chlorophyll a concentration of harvested basins immediately following harvesting, and throughout the remainder of the summer, exceeded those of the baseline SRB's.

Plausible explanations for the increase in chlorophyll a following harvesting were discussed and investigated. These included resuspension of benthic nutrients resulting from harvester turbulence, resuspension of seeds or other particulate matter which could stimulate germination of replacement aquatic vegetation, or a rebound in macrophytic and algal concentrations resulting from a post harvesting reduction in competition for available nutrients and sunlight.

Historically, harvesting activities had been supported with the application of copper sulphate and simazine based sterilents until the recent ban of these products from SRB application necessitated research into alternatives. An investigation into emerging weed and algae management techniques and a review of the effectiveness of weed and algae control methods presently employed by the City of Winnipeg Water and Waste Department was also conducted, with the intent of developing a cost effective SRB management program. The methods reviewed included alternative herbicides for application, SRB aeration, lime treatment, barley straw application, and introduction of sterilized grass carp. In addition, a shoreline raking program was also conducted and reviewed on an experimental basis.

Review of alternative emerging weed and algae control methods indicated that the most promising methods available to supplement or replace the aquatic weed harvesting program included sterilized grass carp and the use of the commercially available herbicides Reglone A and Karmex DF. As sterilized grass carp were not yet commercially available, only pilot studies of Reglone A and Karmex DF were undertaken. A set of water quality indicator parameters were monitored at SRB's in which each of these herbicides had been applied and qualitative assessments were recorded.

Investigation into the effectiveness of the herbicides Karmex DF and Reglone A indicated that both provided promise as competitive means for weed and algae control, and either could prove to be an important supplement to, or a replacement for, conventional harvesting practices. Although the late application of these herbicides in 1996 permitted the collection of limited data following treatment, early indications were that both herbicides provided an effective means of reducing chlorophyll a concentrations. In addition, qualitative field observations indicated that both the Reglone A and Karmex DF applications were effective means of controlling weed and algae. As such, a combination of both herbicide treatment and mechanical harvesting methods is recommended to provide the most effective weed and algae management program.

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1.0 INTRODUCTION

Stormwater Retention Basins (SRB's) have been implemented as hydraulic control structures throughout much of Winnipeg in its developing areas since the 1960's. The flat topography which typifies Winnipeg's landscape make the cost efficiencies generated by these human-made structures appealing to developers. Stormwater Retention Basins are constructed to behave as land drainage reservoirs, and buffer peak runoff rates from developments. The attenuation of runoff hydrograph peaks enables the construction of smaller, more cost effective conduits between SRB's and receiving streams, which are often located several kilometers from the development. Additional benefits realized from SRB's include the provision of primary land drainage treatment, and storage elements during extreme river flooding events.

Stormwater Retention Basins have functioned effectively as hydraulic structures since their inception more than 30 years ago. These facilities are also marketed as having aesthetic value by adding park and waterfront property to developments. In their infancy, SRB's were in fact depicted as recreational facilities, offering opportunities for canoeing, wind surfing, and a variety of other activities. This promotion of SRB's as more than drainage structures has resulted in a perception and service expectation which is difficult, if not impossible to satisfy.

Several factors contribute to the difficulties in satisfying residents' SRB service expectation. For instance, recharge of the basins is primarily achieved through contributions from the land drainage sewers discharging to the SRB's. The runoff contributions from these sewers, although separated from the sanitary system, carry a variety of pollutants such as motor oil and pesticides, as streets and properties are washed with each rainfall event. Although SRB's benefit the environment by reducing the discharge of these pollutants to receiving streams, the result is an accumulation of pollutants which make the basins unsuitable for primary recreation. In addition to water quality concerns, accumulation of sediments results in a soft basin bed which is neither safe or desirable for recreational swimming. These sediments, also accumulate and settle within the basins leading to the aging or eutrophication of the basins, ultimately leading to a weed and algae inhabited wetland. Additional contribution of nitrogen and phosphorus from lawn fertilizers further promotes eutrophication. Heavy accumulation of nutrients in residential SRB's typically results in a hyper-eutrophic condition where weed, algae and odor concentrations are deemed unacceptable by residents.

The City of Winnipeg Water and Waste Department presently operates and maintains 70 Stormwater Retention Basins throughout the City of Winnipeg. During the summers of 1995 and 1996, twenty-one of these were harvested for the removal of aquatic weeds. Due to maneuvering constraints, SRB harvesting is only practical on larger SRB's with wide channels. Harvesting is also limited to SRB's bordered by residential properties, in order to ensure operating resources are applied where maximum aesthetic benefits will be achieved. The harvester itself is a barge mounted weed cutter which collects and removes aquatic vegetation from the SRB's. Once cut, the vegetation is stored in the rear of the harvester and later is unloaded onto a trailer, and hauled to landfill for composting. A sample specification drawings and images of an aquatic weed harvester are available for review in Appendix I.

Unfortunately limitations on the number of harvestable basins exist due to time, availability of equipment, and site conditions at some stormwater retention basins, and as a result the City is forced to conduct aquatic weed harvesting activities according to priority. Harvesting priority is reviewed and revised regularly throughout summer months, and operations are directed dynamically, according to changing water quality conditions in each of the SRB's in an effort to achieve optimum performance during the relatively short harvesting season. The cost effectiveness of the harvesting program is greatly reduced towards the end of summer. Accordingly, activities are typically mobilized in early June, following the germination of aquatic vegetation, and terminate in late August each year.

Harvesting activities had historically been complimented by a chemical treatment program, where small, less accessible SRB's could be provided with effective weed and algae control through the use of sterilents and algicides. However in 1992 and 1995 respectively, Agriculture Canada banned the application of copper sulphate based algicides and simazine based sterilents to SRB's. Both copper sulphate and simazine had been used by Winnipeg in the commercial forms of Cutrine and Princep Nine-T respectively, and had proven to be effective tools for supporting the City of Winnipeg's efforts to control weed and algae growth.

In response to the lack of weed harvesting alternatives, the Water and Waste Department is presently seeking an acceptable alternative to Princep Nine-T. Research into various herbicides and sterilents resulted in the City receiving stormwater retention basin chemical application permits from Manitoba Environment for the herbicides Karmex DF and Reglone A. These herbicides were applied to five SRB's on an experimental basis in 1996, and the results were monitored. The results of the test program were not conclusive at the time, and as such, further testing with application during the spring of 1997 was undertaken with the hope that application during the emergent stage of weeds and algae would provided more conclusive results. The Red River flood event of 1997 resulted in program delays which did not permit the application of Karmex DF and Reglone A to the target SRB's until late June in 1997. Furthermore, budget and staffing limitations did not permit collection of the water quality data required for a quantitative assessment of the effectiveness of the two herbicide alternatives. Despite this, qualitative field observations indicated that both Karmex DF and Reglone A provided effective control of weeds and algae in the targeted SRB's, despite application late in the growing season.

The 70 SRB's within the City of Winnipeg are identified according to a numbering scheme relating to the former city administrative structure which utilized Operations Districts to undertake localized public works activities. Each basin is assigned two numbers separate by a hyphen. The first number indicates the former Operations District which the basin falls within. With the former Operations Districts now dissolved within the existing city structure, the first number remains a good indicator of the approximate region within the city which the SRB is located. The second number is assigned sequentially to each SRB at the time the development, and therefore the SRB, was conceived. As such, the second number typically indicates the relative age of the basin within the former Operations District, and therefore an older basin would typically have a lower second number and a newer basin would have a higher second number. Maps and site descriptions indicating the location of Winnipeg's SRB's are presented in Appendix II.

Although wide variations in physical properties between various SRB's exist throughout Winnipeg's drainage networks, generalizations may be made from the physical characteristics of 55 SRB's which have been documented. The average surface area of SRB's at normal water level is 2.8 hectares with a sample standard deviation of 2.3, and the average water depth is 1.8 meters with a sample standard deviation of 0.349. Typically SRB's have a stone revetment extending 3.5 m horizontally above the normal operating shoreline, and 2.0 m into the water for erosion control purposes, in addition to providing aesthetic quality to the surrounding area. SRB's typically have 7:1 (horizontal: vertical) side slopes from the top of the revetment stone to the bottom elevation of the basin. Although in some cases, according to recently updated design standards, the grade of the side slopes increases to 4:1 at a distance of 3 m into the basin from the shoreline. The shallow side slopes and ending of the stone revetment approximately 2 m into the basin have been design to reduce the potential for accidental immersion into deeper water by children in the largely residential developments that these facilities often service. The recent revision to SRB standard construction specifications included the 4:1 sided slopes beyond 3 m from normal summer shoreline in an effort to reduce solar penetration to the basin bottom, and thereby discouraging the proliferation of submerged macrophytes (UMA Engineering Ltd., 1992).

Although variations in development density and annual precipitation would render a statistical assessment of hydraulic performance parameters meaningless, an average SRB may be generalized for demonstration purposes. SRB's typically comprise approximately 5.5% of their respective drainage areas and have perimeter to area ratios of 0.034 m/m^2. Water turnover occurs approximately 2.8 times per year, and sedimentation rates of 0.03 m per year are also typical. Normally land use in SRB drainage basins is residential, however SRB's are also used in industrial, commercial, multi-family and open area settings. Typically shoreline frontage is split between public and private ownership. Runoff coefficients of 0.22 are typically applied to SRB drainage basins (UMA Engineering Ltd., 1992).

Despite being designed and constructed as hydraulic structures, operational challenges span a wide spectrum of aesthetic, hydraulic and environmental problems. Fountain, pump, conduit, gate and channel operations and maintenance typify the more conventional challenges presented to the City's Water and Waste Department. However addressing aesthetic concerns such as litter clean up, proliferation of aquatic vegetation, and wildlife management also become issues which are typically more difficult to address. Furthermore, large capital improvements are often required for the replacement of revetment stone which disappears over periods of 10 to 15 years due to erosion and stone throwing by residents.

Recent budget limitations, coupled with federal bans on sterilents and algicides which had been historically used, have made delivery of an acceptable level of service to the public increasingly more difficult. SRB aquatic vegetation harvesting had been viewed as a favorable means of satisfying both environmental and aesthetic concerns as it provided a means for the physical removal of the biomass, an therefore to some extent fixed nutrients, without the utilization of chemical application. However, as harvesting was applied to SRB's as the sole method of vegetation control, complaints continued to be received, and in some cases complaints increased as large masses of cut, but unretrieved vegetation would wash up against shorelines, and decompose. The physical awkwardness of the harvester often resulted in substandard performance, particularly during windy conditions. Spatial constraints within small SRB's, and narrow reaches, also limits the number of harvestable basins. Furthermore, a growing percentage of complaints implied that macrophyte and algae regrowth following harvesting was more intense than prior to operations.

In response to these growing concerns this study was undertaken in an effort to observe the impact which conventional harvesting methods has upon certain water quality parameters such as chlorophyll a, turbidity, transparency, pH, and nutrient concentrations in Winnipeg's SRB's, and to investigate alternative means of controlling weed and algae growth in SRB's as either a replacement, or supplemental means to harvesting. As such, a study of the effectiveness of weed and algae management technologies for Stormwater Retention Basins within the City of Winnipeg has been undertaken as the basis of this research project. Effectiveness of traditional methods such as mechanical harvesting was compared with the application of alternative herbicides Karmex DF and Reglone A. Other alternatives such as manual remove of shoreline weeds are also discussed. A review of other potential technologies such as sterilized grass carp, lime treatment, barley straw application, and aeration was also undertaken.

Parameters of interest include chemical and biological indicators of water quality including pH, turbidity, transparency, chlorophyll a, dissolved oxygen, total kjeldahl nitrogen, nitrate-nitrogen, and total phosphorus. Other factors such as cost per hectare of treatment, inspected effectiveness of treatment, and logistical factors such as production limitations and other operational difficulties were also reviewed in the overall assessment of treatment alternatives. 1995 and 1996 data were analyzed and interpreted, however budget and resource limitations prohibited collection of further data in 1997.

Waverley Lakes drainage network SRB's (SRB's # 6-7, 6-8, and 6-9) were selected as test basins from the 1996 data set as they were harvested earliest and provided the most robust data set to observe the impact of the harvesting activities. The Maples drainage network (SRB's #3-2, 3-3, and 3-4) was selected from the 1995 data set as it offered both a robust and extended data set following harvesting, and provided diversity to the Waverley Heights data set. Water quality data for the Waverley Lakes and Maples drainage networks were available in both 1995 and 1996, however the 1995 Waverley Lakes data and 1996 Maples data were not included in the analysis as the data set following harvesting for each of these was too short to develop supportable conclusions. Maps and site descriptions indicating the location of Winnipeg's SRB's are presented in Appendix II.

In addition to the Waverley Heights and Maples drainage networks, the St. Norbert (SRB's # 6-12 and 6-13) and Fort Richmond (SRB's # 6-10 and 6-11) watersheds were analyzed and compared as baseline cases to the test systems for both the 1995 and 1996 data sets. These two systems were selected as baselines as their watersheds offered similar characteristics to the test SRB's and furthermore, neither of the baseline systems had been subject to treatment in 1995, 1996, or in past years.

In summary, the objectives of this study were to:

1) Observe the impact of conventional harvesting methods on chlorophyll a concentrations in Winnipeg's SRB's.
2) Assess the effectiveness of conventional SRB weed and algae management technologies.
3) Investigate alternative means of controlling weed and algae growth in SRB's.
4) Review potential emerging technologies for SRB weed and algae control.

2.0 ECOLOGICAL BACKGROUND

Although designed and constructed as hydraulic structures, Stormwater Retention Basins in Winnipeg are often marketed as aesthetic enhancements to a community by developers to prospective home buyers in residential developments. As a result, residents in areas serviced by SRB's typically foster an expectation for clear, pristine, water bodies which have been marketed to them. This expectation is typically satisfied in the early life of the SRB prior to substantial build up of nutrients and sediments in the basins which ultimately lead to eutrophic conditions five to ten years following initial development. Prior to eutrophic and hyper-eutrophic conditions, residents typically grow accustomed to the relatively sterile state of basins while the basins are still relatively young. Marketing of SRB's as naturalizing wetlands, or bodies of water which naturally evolve into marshland environments, may result in public expectations which are more easily satisfied.

As SRB's mature, the corresponding increase in nutrient concentrations and sediments results in a proliferation of weed and algae in the water body which residents often describe as unsightly and odorous. Satisfying the residents' expectations of clear water, and a relatively sterile aquatic environment becomes increasingly difficult as basins age and the rate of eutrophication increases.

Water quality analysis of Stormwater Retention Basins within the City of Winnipeg indicates that most basins are presently either in a eutrophic or hyper eutrophic state. Eutrophic lakes are defined as those with chlorophyll a concentrations above 10 ug/l and phosphorus concentrations in excess of 0.1 mg/l. Hyper-eutrophic SRB's are those with chlorophyll a concentrations greater than 20 ug/l (Aquatic Research and Developments Inc., 1990). Chlorophyll a is an indicator of photosynthetic activity, whereby a greater concentration implies more photosynthesis is occurring in the basin. Factors such as land use, inflow of water, and water column nutrient concentrations have been linked to chlorophyll a concentrations, and therefore the volume of aquatic vegetation present within a basin. A strong correlation between chlorophyll a concentrations and nutrient levels, specifically total phosphorus and total kjeldahl nitrogen (TKN) concentrations, exists within SRB's (UMA Engineering Ltd., 1992). This relationship is in response to the nitrogen and phosphorus required by aquatic vegetation for the fixation of inorganic carbon. Among other sources, the availability of nitrogen and carbon from the atmosphere, typically results in the concentration of phosphorus being the parameter which regulates the proliferation of weeds and algae in SRB's.

Three species of aquatic macrophytes predominate in Winnipeg's SRB's (Aquatic Research and Developments Inc., 1990). The most common species is *Potamogeton pectinatus* which is estimated to account for 67% of macrophyte abundance. Other common species include *Myriophyllum exalbescens* and *Ceratophyllum demersum* which are estimated to account for 30% and 3% of macrophyte abundance within the city's SRB's, respectively. *Ranunculus aqualtilus* has also been identified in Winnipeg's SRB's in small quantities.

Weed and algae species inhabiting SRB's may be categorized into operationally relevant types. Macrophytes are often classified into two groups. These are submerged aquatic macrophytes, and emergent aquatic macrophytes. Similarly, algae may also be operationally categorized as macrophytic algae, filamentous algae, or planktonic algae (Wallis Environmental Consultants Ltd., 1994). Harvesting activities are typically targeted towards the collection and removal of submerged aquatic macrophytes such as sago pond weed, or macrophytic algae. Harvesting has little success with the control of filamentous or planktonic algae, and emergent aquatic macrophytes such as cattails or bulrushes must be derooted utilizing a cultivating head or manual labor to remove the entire plant or rapid regrowth will occur. Derooting activities are typically limited to one or two meters from shoreline as the harvester tends to beach in the shallower water any closer to the shoreline. Removal of emergent aquatic macrophytes in shallow water and upon the shoreline is a labor intensive and difficult task. Control of emergent aquatic macrophytes may also be done using herbicides such as Amitrol-T.

Control of filamentous and planktonic algae had historically been successfully undertaken in Winnipeg utilizing sterilent and algicide applications. If maintained in a sustainable balance, natural controls and more recently biomanipulation provide an alternative means to chemical application for filamentous and planktonic algae control. Biomanipulation is defined as "a series of manipulations of the biota of lakes and their habitats to facilitate certain interactions and results which we as lakes users consider beneficial - namely the reduction of algal biomass and, in particular, of blue greens" (Shapiro et al., 1975). Biomanipulation techniques utilize a trophic-cascading approach to create environmental factors which favor the proliferation of zoo-plankton which feed upon algae. Consequently biomanipuation methods are effective in controlling phytoplankton densities, but are limited or ineffective means of managing macrophytes.

In a typical lake or SRB food chain, nutrients are recycled by benthic organisms and consumed by algae. Algae in turn are preyed upon by zooplankton which is consumed by planktivorous fish. Planktivorous fish are then eaten by piscivorous fish. Disruption of this food chain can therefore result in an imbalance in the aquatic environment. A deficiency in piscivorous fish for instance could lead to an increase in planktivorous fish, thereby resulting in a drop in zooplankton and a subsequent increase in algae, particularly where a steady supply of nutrients continue to be introduced to the water column as is the case with SRB's (Wallis Environmental Aquatics Ltd., 1995).

Biomanipulation techniques attempt to exploit the relationship between species in an effort to manage the proliferation of undesirable species, which in the case of SRB's is algae. Increases in the population of desired species are encouraged in an effort to trigger reactions up or down the food chain, thereby resulting in a decrease in algae abundance. The suitability of these methods for Winnipeg's Retention Basins is uncertain given the short, intense growing season of SRB's, which typically include wide and rapid variation in weed and algae concentrations.

The promotion and marketing of SRB's as pristine water bodies as opposed to naturalizing wetlands or drainage structures has resulted in a perception and service expectation by residents which is difficult, if not impossible to satisfy. In response to these expectations, approximately one third of these basins are mechanically harvested for the removal of aquatic weeds each summer. In addition, historically effective chemical means utilized by the City of Winnipeg have included the use of copper sulfate based algicides, or simazine based sterilents. Commercially available algicides and sterilents included Cutrine and Princep Nine-T respectively. These products had proven to be an excellent compliment to mechanical removal methods prior to the recent ban of their use in SRB's.

Despite these efforts to manage and control the biomechanisms within SRB's, the ultimate measure of the program's success is public perception and feedback. Chlorophyll a concentration provides a quantitative indication of photosynthetic activity within a water body, however qualitative measures such as a reduction in residents' complaints, positive feedback, and an observable aesthetic improvement in the SRB are more precise indicators of program effectiveness. Although social influences and public feedback such as political pressure for action, and the nature and frequency of complaints are difficult to quantify, these factors weigh heavily upon decision makers and must be taken into account when assessing alternative control measures.

3.0 CONVENTIONAL MANAGEMENT TECHNIQUES

Conventional methods of aquatic vegetation management have traditionally been either chemical or mechanical in nature. Historically effective chemical means employed by the City of Winnipeg have included the use of copper sulfate based algicides, or simazine based sterilents. Commercially available algicides and sterilents included Cutrine and Princep Nine-T, respectively. These products had proven to be an excellent complement to mechanical removal methods until an Agriculture Canada ban on their application to public waterways occurred 1992 and 1995 respectively.

As a result of the product limitations imposed by Agriculture Canada, the only conventional control method which remained available to the City of Winnipeg for its SRB vegetation management program was mechanical, and manual removal techniques. Mechanical removal utilizes the contracted services of an aquatic weed harvester operator, whereas manual weed removal is accomplished through shoreline raking.

3.1 Aquatic Weed Harvesting

Mechanical weed harvesting may be accomplished using a variety of commercially available harvesters. These devices are typically built upon a barge mounted hull and utilize diesel driven paddle wheels as their power train. The paddle wheels are located at the approximate midpoint of both port and starboard sides of the hull, which permits forward, reverse, and rotational thrust by throttling either paddle wheel appropriately. Harvesters are typically require a minimum water depth of 0.4 m to operate.

The harvester utilized in the Winnipeg aquatic weed control program was the H7-400 Aquatic Plant Harvester manufactured by Aquasphere Technologies Inc., formerly Lakescape International Ltd., of London, Ontario. The H7-400 has a length dimension of 7.6 m without the cutting head, or 10.6 m with the cutting head fully extended. The unit's operating width is 4.5 m, and has a shipping width of 2.9 m with the paddle wheels removed to accommodate transfer on municipal roadways. A 32 kW (43 horsepower) diesel powerplant drives the harvester's two paddle wheels and cutting head. Storage capacity is 11.5 cubic meters or 3.2 wet tonnes of vegetation (Lakescape International Ltd., 1989). Other manufacturers of aquatic weed harvesters include Aquarius Systems of North Prairie, Wisconsin. Aquarius Systems manufactures a series of harvesters including the EH-220 Aquatic Plant Harvester. Example specification drawings for both the H7-400 and EH-220 aquatic weed harvesters are presented in Appendix I.

The operator controls the harvester from an elevated platform and steers the cutting head towards areas of dense vegetation. In cases where weed growth is distributed over a large target area, the harvester transverses the water body in a grid like manner, by harvesting the entire surface area with a series of parallel cut lines, followed by a second set of cut lines perpendicular to the first. Photographs of the weed harvester and its operation are available in Appendix I.

Cutting of the weeds is achieved by the harvesters cutting head which is 2.15 m wide and 1.5 m high. Mounted around the cutting head's perimeter are 100 mm sickles or triangular steel teeth, which cut the vegetation to a maximum depth of 1.5 m using a lateral oscillating motion, which is also driven by the harvester's diesel powerplant. The cut vegetation is then transferred via conveyor to the rear of the harvester for storage until full. Once the onboard storage has been filled to capacity, the harvester returns to shore, and the aquatic vegetation is unloaded onto a conveyor trailer. The vegetation is then hauled, via the trailer, to landfill or a nearby landscaping operation for composting.

SRB harvesting may only be practically undertaken on larger SRB's with wide channels. Narrow basin geometry, or smaller basins do not provide adequate area for the harvester to maneuver within, or the amount of vegetation which can be practically removed from these basins does not warrant mobilization costs. Harvesting is also limited to SRB's bordered by residential properties, in order to ensure operating resources are applied where maximum aesthetic benefits will be achieved.

Removal of submergent and emergent macrophytes may also be achieved by using a cultivating head which is interchangeable with the harvester's cutting head. The cultivating head available for the H7-400 is 1.2 m wide, however cultivating heads as large as 2.4 m are available for larger harvesters such as the H10-300, a 52 kW (70 horsepower) version of the

H7-400. The brush like cultivating head rotates rapidly, and as aquatic vegetation is contacted it is derooted. The derooted matter must be collected following cultivation. Unsubstantiated manufacturer's claims imply that weed removal via cultivation results in slower regrowth within the SRB as germination of new vegetation is necessary.

Limitations on the number of harvestable basins during a season exist due to time, availability of equipment, and site conditions at some stormwater retention basins. Furthermore, harvesting closer than 3 m from the shoreline is typically impractical as the harvester tends to beach in the shallower water near the shoreline. Perpendicular approaches to the shoreline have been attempted in the past, but have proven to be time consuming and lead to premature wear on the harvester's components as the cutting head and conveyor belting come into contact with the shoreline revetment stone.

As a result of these operational limitations, the City is forced to conduct aquatic weed harvesting activities according to priority. Harvesting priority is reviewed and revised regularly throughout summer months, and operations are directed dynamically, according to changing water quality conditions in each of the SRB's in an effort to achieve optimum performance during the relatively short harvesting season. The cost effectiveness of the harvesting program is greatly reduced towards the end of summer as weed and algae growth has slowed or ended. Accordingly, activities are typically terminated at the end of August each year.

3.1.1 Aquatic Weed Harvesting Program Efficiency

Aquatic vegetation harvesting provides an environmentally sound means of short term weed control in large, geometrically simple SRB's. Macrophyte control is undertaken without the introduction of chemical herbicides or sterilents, and provides the additional benefit of physically removing the fixed nutrients stored within the biomass from the SRB, and converting them to compost.

Under favorable weather conditions, an SRB is typically harvested within two to three days, depending upon its size, geometry, and the density of weed growth. In 1998, vegetation removal rates ranged between a maximum of 36.3 wet tonnes/hectare and a minimum 1.1 wet tonnes/hectare in SRB's 3-2 an 6-15 respectively (Appendix II). 1998 mobilization costs have been bid at $637.50 per SRB plus $1,222.00 per harvested hectare. Project mobilization costs of $1,275.00 were also bid on an annual basis. This translates to a 1998 tender bid price of $87,345.00 plus tax, by the successful contractor for the harvesting of 21 SRB's in the City of Winnipeg. Other harvesting related expenses typically incurred by the city each year include the maintenance and repair of launch ramps, green space, boulevards, and sidewalks, all of which are often damaged during launch and removal of the harvester.

Operational limitations with harvesting include SRB size, SRB geometry, and vulnerability to environmental conditions. In addition to being operationally constrained by periods of rainfall, wind may also complicate operations, and in some instances result in unacceptable performance which may even prove aesthetically counterproductive. Moderate to strong cross wind conditions cause a rotation and lateral movement of the harvester which results in uneven vegetation removal, and missed strips of weed mass remaining. Furthermore, and more problematic is the tendency for cut masses of vegetation to escape the harvester's conveyor system, allowing them to drift and remain on the water body uncollected. The tendency for these masses of vegetation to escape uncollected is in part due to the additional wave action prevalent on SRB's during periods of high wind, and the inability of the operator to keep the harvester on course during windy periods.

3.1.2 Aquatic Weed Harvesting Qualitative Assessment

When applied under proper environmental conditions, aquatic vegetation harvesting may provide effective short term macrophyte control in SRB's with wide basin geometry and surface areas of approximately 1.2 hectares or larger. Despite this, harvesting may result in an unacceptable number of cut, but uncollected, floating masses of vegetation. These masses of vegetation, referred to as floaters, typically collect upon shorelines and decompose causing unsightly and odorous conditions which may actually result in an increase in residential complaints following harvesting.

The aquatic weed harvester's inability to operate in waters shallower than 0.4 m further results in a 3 meter to 5 meter wide unharvested band around the SRB perimeter. This unharvestable shoreline growth represents the most visible and sensitive area of the SRB to residents as it is immediately adjacent to their properties. In addition to the unsightly and odorous nature of the shoreline growth, it further acts as a net for floating debris and additional vegetation cut, but not collected, by the harvester.

Regrowth of vegetation within SRB's typically occurs approximately four weeks following harvesting. Although providing residents with a relatively short period of relief from the overabundance of aquatic vegetation, operation of the harvester appears to satisfy most residents that the problem of excessive weed and algae growth has been addressed, and that the city has fulfilled its service obligation to them.

3.2 Shoreline Raking

Of primary concern to residents living adjacent to SRB's is the density of shoreline vegetation immediately bordering their property. The condition of this shoreline perimeter is often described as unacceptable by residents as weed growth tends to be heaviest in this area as the shallow water permits the greatest amount of solar penetration to the basin bottom. The condition of the shoreline is further aggravated by the harvester's inability to remove vegetation any closer than 3 m from the shoreline. In addition, wind action, tends to collect and concentrate floaters along the shorelines, which subsequently become entangled with the uncut vegetation around the SRB's perimeter.

In an effort to address the unsightly condition of the SRB perimeters, a shoreline raking pilot program was initiated in 1997. This program was contracted with a local youth program to employed students for the manual removal of shoreline vegetation with rakes. The high labor component and low removal rates made this type of removal expensive. Logistical and coordination failures further plagued the program, often resulting in results counterproductive to the intended objective of improved aesthetics.

3.2.1 Shoreline Raking Program Efficiency

Contracted rates of $1.29/linear meter were negotiated and shoreline raking was approved for six basins on a trial program during the summer of 1997. Removal masses were not documented, however although large qualities of vegetation were collected, a significant amount of growth was left behind. The remaining vegetation was difficult to remove as it tended to flow through the rakes. Removal of masses in areas of dense growth was more easily achieved as the vegetation tend to become tangled with the rake as it was drawn over it. This mechanism of removal was aggravated by the need to untangle the weed growth which had collected with each draw of the rake.

Following withdrawal of the vegetation from the SRB water body, the vegetation was left on the revetment stone by the work crews for a period of two days in order to allow drying prior to returning for collection and disposal of the biomass. Collection of the dried vegetation into garbage bags was again achieved manually. Removal of the garbage bags was done by city forces who disposed of them at the nearest landfill.

3.2.2 Shoreline Raking Qualitative Assessment

Efforts to coordinate harvester activities with the shoreline raking program, and enable raking of weeds directly onto the harvester head while it floated offshore failed, thereby requiring the manual retrieval of the dried waste vegetation. The negative aesthetic impact of leaving weed masses on the shoreline revetment to dry immediately resulted in an increase in complaints by residents. Furthermore shoreline raking's success at derooting and removing of aquatic vegetation was limited.

Logistical errors by the contractor further resulted in resident complaints as large areas of dried vegetation were overlooked during retrieval, and SRB's which were not included in the contract were raked without notification. The drying weed masses were not initially removed by the contractor at the SRB's not included in the contract, and the waste was left on the shoreline until complaints were received.

4.0 EMERGING TECHNOLOGIES AND METHODS

In addition to conventional weed and algae control methods, a number of emerging technologies and methods, at various stages of commercial availability, warrant discussion. These methods include alternative herbicides for application, SRB aeration, lime treatment, barley straw application, and introduction of sterilized grass carp. Although the approach for emerging aquatic vegetation control methods varies from water column sterilization to ecosystem management, most emerging techniques utilize chemical or biological control mechanisms. Emerging chemically based methods are primarily classified as herbicides as opposed to algicides or sterilents.

4.1 SRB Herbicide Pilot Program

With the 1992 and 1995 Agriculture Canada bans on application of copper sulphate based algicides and simazine based sterilents, the commercially available products Cutrine and Princep Nine-T were no longer available as weed and algae control tools on the City of Winnipeg's SRB's. In response to the resulting reduction in weed and algae management techniques available, investigation into emerging herbicide alternatives was identified as the most appropriate course towards identifying new methods of managing phytoplankton and macrophytes under non-harvestable conditions. Non-harvestable conditions include small basins with limited maneuvering area, and growth in shallow reaches of SRB's. Research into replacement products revealed two commercially available alternatives, Karmex DF and Reglone A, were potential alternatives suitable for SRB application. As such, closer study of each was undertaken including pilot studies which investigated the impact both Reglone A and Karmex DF had on aquatic vegetation during field tests conducted in 1996 and 1997.

4.1.1 Karmex DF

Karmex DF is a diuron based herbicide manufactured by E.I. du Pont de Nemours and Company Agricultural Products in Wilmington, Delaware, USA. Canadian distribution of the product is by DuPont Canada Inc. of Mississauga, Ontario.

Diuron concentration in Karmex DF is 80% and is distributed in the form of dispersible granule (Manitoba Agriculture, 1991). Karmex DF is typically mixed with water and applied as a spray to the surface of the ground, a pond or a dugout for control of weeds and algae (Manitoba Agriculture, 1997). Effects are typically not observable for a period of a week or more, and do not become apparent until the chemical is absorbed into the vegetation. Application to SRB's has been successfully achieved by immersing a cloth sack filled with the granular herbicide into the water body and dragging it along side a small power boat.

Recommended application rates of Karmex DF range from 6.25 kg/hectare-meter of depth to 25.0 kg/hectare-meter of depth, depending on the degree and duration of control desired

(DuPont Canada Inc., 1996). Application rates in Winnipeg SRB's have initially been specified at 25.0 kg/hectare-meter of depth, with application times limited to periods of low wind and no rainfall forecast. Application of Karmex DF is not permitted in water intended for consumption, and irrigation using water treated by Karmex DF is not recommended for a period of one year.

Unit application rates of $932.21/hectare have been bid for both the 1997 and 1998 treatment seasons by a licensed contractor. These costs reflect both the product and labor component of Karmex DF application. Shoreline treatment as opposed to full surface treatment offers a reduction in the effective cost of Karmex DF treatment.

Qualitative inspections of basins treated with Karmex DF imply that it is a highly effective means of controlling weed and algae growth for extended periods when applied at concentrations of 25.0 kg/hectare-meter of depth. SRB's treated at this concentration saw a dramatic decrease in weed and algae content, and remained clear of vegetation for the remainder of the growing season. Browning of leaves on one tree planted near the perimeter of an SRB treated with Karmex DF was reported in 1997. Regrowth of vegetation appeared to proceed normally in SRB's treated by Karmex DF in 1998. Further discussion and quantitative assessment of the effectiveness of Karmex DF is presented in Section 5.2.

4.1.2 Reglone A

Reglone A is a diquat based liquid herbicide manufactured by Zeneca Agro of Stoney Creek, Ontario. The concentration of diquat in Reglone A is 200 grams/liter of liquid herbicide. Reglone A is a non-volatile herbicide used for the control of aquatic weeds without impact upon other aquatic life or animals. Control of susceptible weeds typically occurs within 1 to 2 weeks of application. Temporary control of the *Cladophora, Spirogyra, and Pithophora sp.* algae is also achievable using Reglone A (Zeneca Agro, 1995).

Irrigation using water treated by Reglone A is not recommended for a period of five days following application. This compares to a one year moratorium on irrigation using water treated with Karmex DF. Utilizing a herbicide with the shorter residency time is of tremendous benefit as it limits the period of liability for grass kills due to rising lake levels. Extended weather forecasts will usually provide the operating agency with a sufficient outlook as to the probability of receiving enough rainfall within the next five days to raise the SRB water level beyond the elevation of the revetment stone, a level which corresponds to a 25 year rainfall event. As irrigation with Karmex DF is not recommended for twelve months following application, the probability of turf damage appears to be considerably lower with Reglone A application. In an effort to establish the residency time of the test herbicides in SRB's, and therefore the risk associated with the use of Reglone A and Karmex DF, direction was given to test 1998 SRB samples for diquat and diuron concentrations prior and subsequent to their application.

Surface application of Reglone A may be achieved through spraying a mixture of 1 part Reglone A and 4 parts water over the SRB water surface. An application concentration of 22 liters/hectare is recommended for control of weeds in 1.5 m of water or less. Accordingly, 22 liter/hectare was the application rate specified for the pilot activities undertaken.

Unit application rates of $568.83/hectare have been bid for both the 1997 and 1998 treatment seasons by a licensed contractor. These costs reflect both the product and labor component of Reglone A application. Shoreline treatment as opposed to full treatment offers a reduction in the effective cost of Reglone A treatment.

Qualitative visual inspections of SRB's receiving Reglone A treatment during pilot activities indicated that Reglone A provided and effective means of weed and algae control in the targeted SRB's. A quantitative and qualitative assessment of Reglone A applications in Winnipeg is presented in Section 5.2. Although Reglone A results were less dramatic than those achieved with Karmex DF, lower cost, no reports of damage to perimeter vegetation, and a shorter specified residency time of five days provide benefits which offset the greater performance observed with Karmex DF.

Application of Reglone A to Beaumaris Lake by the City of Edmonton in 1988 was documented as providing a short term reduction in chlorophyll a concentrations and was credited with the elimination of large algae mats. However, an explosion of chlorophyll a concentrations to the highest levels observed during the study period occurred within fifteen days of application (I.D. Engineering Company Ltd, 1988). During the period immediately following application, chlorophyll a concentrations within Lake Beaumaris decreased from pre-application concentrations of 112 ug/l to 60 ug/l ten days later, however five more days later chlorophyll a concentrations had increased to 150 ug/l.

Researchers hypothesized that the increase in chlorophyll a concentrations on Lake Beaumaris following Reglone A application was the result of the dead algae releasing phosphorus into the water column, only to be reused by new algae. This hypothesis was supported by the measured increase in total dissolved phosphorus from 58 ug/l to 155 ug/l during the two week period following Reglone A application.

4.2 Aeration

Proliferation of weed and algae in SRB's is often aggravated by the lack of predation from herbivorous fish species. Fish species which would typically maintain a healthy and balanced ecosystem within the SRB are often suffocated as algae and other organisms die and sink to the bottom of the basin. The subsequent decay of this biomass consumes oxygen. Winter fish kills frequently occur in SRB's throughout the City of Winnipeg as ice cover further aggravates the situation by eliminating reaeration from the atmosphere through the lake surface.

Oxygen depletion starts at the bottom of the SRB, with increased concentrations occurring closer to the surface. One proposed method of providing a healthier aquatic environment for herbivorous fish includes the installation of aeration diffusers, supplied by shore mounted compressors. Air pressures of 35 kPa to 70 kPa and volumes of approximately 70 to 280 liters per minute, per hectare, are required to properly aerate a typical SRB. The diffuser hose is perforated and weighted with a specific gravity slightly above one to enable it to "float" off of the SRB bottom in the sediment heavy bottom of the water column. Approximately 30 m of diffuser hose is required per hectare of SRB (Alberta Agriculture, Food and Rural Development, 1998).

Operating costs of the facility are estimated to be between $400 and $500 annually, including hydro and materials. Typical initial costs are estimated at approximately $ 15,000 to $ 20,000 per basin, depending SRB size and geometry (John Hinde Company, 1997).

Application of this technology has yet to be undertaken within Winnipeg, and as such local operational experience with SRB aeration remains unavailable. Accordingly the impact of aeration on local SRB environments remains untested and uncertain however the potential for ecosystems imbalances exists. Increases in dissolved oxygen concentrations caused by aeration may result in nitrification (ie. the conversion of ammonia to nitrate). This increase in nitrate-ion concentration could result in algal imbalances and cause a proliferation of cyanobacteria, or "blue green algae". Pilot testing and close monitoring of the impact of aeration on local SRB ecosystems in therefore recommended prior to acceptance or wide spread implementation of this technology.

4.3 Sterilized Grass Carp

The use of triploid grass carp, or White Amur (*Ctenopharyngodon idella*), as a biological alternative to chemical and mechanical weed management methods has been proposed to potentially achieve financial, environmental, and public health benefits. Investigation into the viability of weed management through the utilization of grass carp has been under study by the Alberta Agriculture's Aquaculture Section since 1987 by the Committee on Biological Control of Aquatic Vegetation. This method proposes the introduction of sterilized grass carp into non native environments and as such has undergone an intensive risk assessment for the following reasons (Alberta Agriculture, Food and Rural Development, 1997):

1) The potential risk to native flora and fauna in adjacent or contiguous waters if exotic grass carp were to escape and become established in non native ecosystems.
2) Pressure by political, economical, and sociological interests to investigate and expand biological weed control alternatives.
3) Interest has been demonstrated by neighboring provinces who have indicated potential for participating in similar biological weed control programs provided natural ecosystems would not be compromised.

Grass carp are indigenous to coastal rivers in Siberia and China, but have also been extensively cultured in Malaysia, Singapore, Borneo, Indonesia, Taiwan, Hong Kong, the Phillippines, and non native areas of China. In North America, grass carp has been licenced to control aquatic vegetation in irrigation canals and reservoirs in Mexico and 37 American states.

Experience to date indicates that variety of aquatic weeds are effectively controlled by grass carp including chara, water plantain, sago pondweed, soft-stemmed pondweed, small-leafed pondweed, Canada waterweed, and filamentous algae. Biomass consumption rates are dependant upon fish size, fish numbers, water temperature, weed density, species composition and diversity within the pond, and duration of pond residency for the grass carp. Smaller fish, between the ranges of 25 cm and 40 cm in length will typically consume 35% to 50% of their body weight daily. Larger fish, those greater than 45 cm in length, will typically consume 20% to 30% on their body weight on a daily basis. Grass carp may grow to as large as 15 kilograms. Weed control rates through grass carp utilization have been found to be as high as 80%, however in basins with few palatable plants, weed control has been recorded as low as 20% (Alberta Agriculture, Food and Rural Development, 1997).

Fish survival during summer months has been found to be between 91% and 97%. During winter months the fish are transferred to aerated overwintering dugouts where survival rates of between 82% and 100% have been recorded. Predation from species such as the Northern Pike, may be addressed by netting or angling to control this species prior to stocking with grass carp, where known to be prevalent. Great blue herons, seagulls, mergansers, kingfishers, and cormorants make up the primary bird predators which may threaten a grass carp population. In a non predatory environment, with proper wintering conditions, grass carp may live as long as ten years.

Concern over the proliferation of grass carp in non traditional habitats is addressed through the sterilization of the fish by subjecting the fertilized eggs to pressures of 55 MPa for one minute and thirty seconds. This pressure treatment results in the fish developing with chromosomes in sets of three (triploid) instead of two (diploid). The impact of this mutation is that the fish are normal in all respects expect that they are unable to reproduce (Nico, 1996). Concerns with respect to the introduction of diseases into the native fish population via exotic foreign fish species such as the grass carp have been addressed through annual testing for important parasite, bacterial, and viral diseases. To date, all tests have indicated an absence of important diseases in the Albertan grass carp population.

The cost of certified sterilized and disease inspected fish is approximately $20 each. In order to successfully achieve weed removal rates of approximately 15 tonnes per month, and assuming a consumption rate of 25% of body mass, approximately 135 carp would be required for a typical SRB. This translates to an annual operating budget of $2700 for an SRB requiring weed removal rates of 15 tonnes per month assuming annual replacement of the entire grass carp population. Provision of over-wintering facilities, or over-winter survival of grass carp in SRB's could result in a substantial reduction in these estimated annual costs.

China and other Asian countries have introduced grass carp into ponds with other fish species exhibiting different feeding requirements in an effort to eradicate a larger volume and variety of aquatic vegetation. Species such as silver carp, bighead carp, black carp, and common carp have all been used to consume microscopic algae and other undesirable plant and animal matter. This diversity of cultures permits more effective conversion of plant matter to fish flesh and provides a more robust and ecologically balanced pond.

4.4 Lime Treatment

During the summers of 1988 and 1989, the City of Edmonton investigated the effect that lime ($Ca(OH)_2$) application had on the concentration of algal biomass and nutrients in Stormwater Retention Basins under their jurisdiction (I.D. Engineering Company Ltd, 1988). Five SRB's were treated with two forms of lime, $Ca(OH)_2$ and $CaCO_3$, at varying dosages. Application of $Ca(OH)_2$ resulted in a significant reduction in nutrient concentrations and algal biomass. These results were supported by reductions in total phosphorus and chlorophyll a concentrations. Application of $CaCO_3$ had no significant impact upon phosphorus or chlorophyll a concentrations. The reason for the variation in performance between $Ca(OH)_2$ and $CaCO_3$ was unknown to the authors, however it was suggested that the small sample size of their data set was responsible for the lack of a distinguishable trend between $CaCO_3$

applications and total phosphorus or chlorophyll a concentrations within the targeted SRB (Prepas and Babin, 1989).

The study concluded that $Ca(OH)_2$ form of lime held promise for the reduction of algal biomass and nutrients in SRB's. The study further identified that a reduction in SRB pH's of up to 1.5 units were observed within two days of lime application. The magnitude of the pH increase was dependent upon the initial alkalinity of the lake, and the dosage of lime applied.

4.5 Barley Straw

Study by the Aquatic Weeds Research Unit near Reading, England implies that the presence of rotting Barley Straw can result on a reduction in unicellular and filamentous algae (City of Winnipeg Parks and Recreation Department, Insect Control Branch, 1995). The observations on which this study was based were made in both laboratory cultures and field environments. Although the control mechanism at work was not understood by researchers, it was hypothesized that as the straw rotted, the lignin is released and oxidizes to quinons which subsequently produce humic substances. Once produced, the humic substances may produce oxygen through a catalytic process, which could damage the algal cells.

The quantity of barley required to significantly impact algal production was observed to be approximately 10 grams per cubic meter of water. It is anticipated that larger quantities could provide greater effectiveness than that observed in the initial study. The effect of the submerged straw was not observed until it had been soaking for approximately one month. The effectiveness of the barley straw was observed to increase for a period of approximately six months, after which time, the effectiveness diminished. All species of algae appeared to be impacted by the presence of the barley straw except *Chara spp.* which may be resistant. No adverse impact on higher plants or fish species was observed.

As the traditional method of algae control, specifically the utilization of copper sulfate based algicides, was no longer available to the City of Winnipeg, the Insect Control Branch of the Parks and Recreation Department undertook its own investigation into the suitability of using submerged barley straw bails in SRB's as an algal inhibitor (City of Winnipeg Parks and Recreation Department, Insect Control Branch, 1995). The results of this investigation implied that application of barley straw at a rate of 25 g/m^3 had no significant impact on algae growth during either of the 1992 or 1993 growing seasons.

Researchers from the Aquatic Weeds Research Unit hypothesized that the discrepancy in study results may be due to the presence of the 5 m to 6 m wide black polyethylene geotexile fabric surrounding the Winnipeg test SRB's perimeter. The Aquatic Weeds Research Unit speculated that anti-oxidizing agents known to be present within black polyethylene could be responsible for inhibiting oxygen production from the decomposing straw.

5.0 CASE STUDY

In an effort to quantitatively establish the impact harvesting has upon aquatic vegetation within Stormwater Retention Basins, six parameters were selected as water quality indicators. Chlorophyll a concentration was selected in an effort to gauge the botanical activity within the basins, turbidity and transparency were measured as indicators of water clarity, and pH was measured in an effort to provide some feedback regarding the impact which a given treatment may have upon the SRB's aquatic environment. As pH and alkalinity levels are dependent upon the quantity of CO_2 dissolved within the water column, pH values were collected and analyzed as turbulence associated with any treatment activity has been hypothesized as causing the resuspension of benthic CO_2 and thereby increasing the pH of the SRB (Prepas and Babin, 1989). Total phosphorus, total kjeldahl nitrogen, and nitrate-nitrogen were also measured prior and subsequent to harvesting as resuspension of benthic nutrients was also hypothesized. Analysis of these parameters was undertaken on samples collected throughout the summers of 1995 and 1996 and results were compared with baseline SRB's where no treatment had taken place. The raw data collected and analyzed is presented in Appendix III.

SRB's function as open systems, and therefore the data collected is by nature vulnerable to numerous influences external to any relationship under study. Such influences include, but are not limited to, sporadic runoff and sediment loadings resulting from rainfall events, irregular nutrient loadings following fertilization of surrounding properties, and sunlight and temperature variations resulting from weather and seasonal variations. Accordingly, data collected should be viewed and interpreted with reservation prior to establishing trends or identifying relationships between any given activity and the water quality observed following that activity.

Test SRB's for harvesting were SRB's 6-7, 6-8, and 6-9 in 1996, and 3-2, 3-3, and 3-4 in 1995. In addition to these drainage networks, SRB's 6-10, 6-11, 6-12, and 6-13 were analyzed and compared as baseline cases to the test systems for both the 1996 and 1995 data sets. SRB's 6-10, 6-11, 6-12, and 6-13 comprise two smaller land drainage catchments with SRB's 6-10 and 6-11 servicing Fort Richmond, and SRB's 6-12 and 6-13 servicing St. Norbert (Appendix II). These two systems, both located in South Winnipeg, were selected as baselines as their watersheds offered similar characteristics to the test SRB's and furthermore, neither of the baseline systems had been subject to any treatment in 1995, 1996, or in previous years.

Different SRB drainage systems were selected for comparison in 1995 and 1996 as variations in the harvesting schedule had occurred. Although necessary to ensure that the longest period of analysis could follow harvesting for each of the test basins, the variation in drainage systems provided the additional benefit of diversifying the test sample, thereby providing a more robust data set. SRB's 6-7, 6-8, and 6-9 comprise the Waverley Lakes drainage network and have surface areas of 2.63 hectares, 1.29 hectares and 1.50 hectares respectively. These basins provide land drainage services to the Waverley Heights neighborhood in South

Winnipeg. SRB's 3-2, 3-3, and 3-4 are part of the Maples drainage network in North Winnipeg, and have surface areas 3.40 hectares, 4.07 hectares, and 2.66 hectares respectively. Water quality data for the Waverley Lakes and Maples drainage networks was available in both 1995 and 1996, however the 1995 Waverley Lakes data and 1996 Maples data was not included in the analysis as the data set following harvesting for each of these systems was too short to develop supportable conclusions.

Further analysis of SRB's treated with the herbicides Karmex DF and Reglone A also took place in 1996, however late application of the herbicides only permitted collection of one set of data following application. As a result, earlier application of herbicides took place in 1997, in an effort to both provide the treatment benefits earlier, and for a longer period, and also in order to better monitor the impact of herbicide treatments on SRB's. Unfortunately resource constraints did not permit a quantitative analysis of any treatment methods in 1997, however qualitative field assessments and observations indicated favorable results. As such, early application and further SRB water quality analysis of herbicide treated, harvested, and baseline SRB's is recommended for 1998.

5.1 Materials and Methods

SRB water column sampling was conducted biweekly from central points on each water surface by using a canoe for access. Surveys conducted alternated between intensive and routine programs. Common to both programs was a visual inspection of SRB's and sample collection. Intensive and routine sampling programs differed from one another in the number of parameters each sample was analysed for.

5.1.1 Visual Inspections

The visual inspection component of the biweekly data collection program comprised of observing and documenting incidents of excessive floating algae, weeds, and cattail growth. Observation of other aesthetic concerns such as garbage or the accumulation of extraneous debris in, or around, the SRB's was also noted. Identification of Purple Loosestrife growth around banks and in the immediate vicinity of SRB's was also documented and the appropriate authorities notified. Documentation, and notification of the presence of noxious odours, abnormally low water levels, or any other apparent abnormalities was also undertaken when necessary.

Visual observations were summarized and each SRB was categorized and rated according to the following criterion:

Excellent:
- banks were in good condition
- little visual evidence of weeds algae or debris
- good water clarity

Satisfactory:
- basins in residential areas with moderate amounts of algae,

weeds and/or debris.

- basins in non-residential areas with excessive algae and/or weed growth that do not require immediate action because of location.

Unsatisfactory:
- basins in residential areas in poor condition with excessive algae and/or weed growth, or requiring debris clean up.

Documentation and reporting of any unauthorized activities occurring on SRB's or their surrounding areas was also undertaken during the visual inspections. Such activities would include excavation of the SRB, use of SRB water for irrigation by private home owners, draining of swimming pools into basins, or the dumping of debris or excavated materials by contractors.

5.1.2 Sampling and Analysis

The SRB water column was sampled from the surface to approximately 0.6 meters depth by slowly lowering the sample bottle by hand or using a vertical water sampler. Basin water was collected using procedure from two representative locations in the center of the SRB and composited into one sample for analysis. Either a routine or intensive sampling program was undertaken on a biweekly basis, with each type of program being staggered of the course of the summer months between May and August. The sampling programs differed in the number of parameters measured for each. Routine survey parameters included sample time and date, total suspended solids, transparency, fecal coliform, and chlorophyll a. Intensive survey parameters included sample time and date, depth of water (m), temperature (Celsius), pH, dissolved oxygen (mg/L @ surface, mid-depth, bottom), total suspended solids (mg/l), turbidity (ntu), transparency (m), chlorophyll a (ug/L), fecal coliform (colonies/100mL), total phosphorus (mg/L), total kjeldahl nitrogen (mg/L), and nitrate-nitrogen (mg/L). Of these parameters, sample time and date, depth of water, temperature, pH, dissolved oxygen, and transparency were collected during field analysis, and all others were determined during laboratory analysis by the City of Winnipeg Water and Waste Department's Laboratory Services Division (Scales, 1993). Total suspended solids, fecal coliform, depth, and temperature data were not included in this study.

5.2 Effectiveness of Harvesting

Chlorophyll a data collected on harvested basins in 1996 is compared to the baseline SRB concentrations in Figures # 1 to 3. Throughout this analysis, Fort Richmond baseline SRB's refers to SRB's 6-10 and 6-11, and St. Norbert baseline SRB's refers to SRB's 6-12 and 6-13 (Appendix II). Data presented for the baseline systems are averages of the values collected for both SRB's in each of the baseline SRB systems.

In 1996, initial chlorophyll a concentrations were tested and found to be the lower in each of the test SRB's than in the baseline SRB's prior to harvesting. Subsequent to harvesting activities, no reduction in 1996 chlorophyll a concentrations was observed in any of the test basins, despite the removal of aquatic vegetation. Chlorophyll a concentrations actually increased substantially in two of the three test basins immediately following harvesting operations. Furthermore, post harvesting chlorophyll a concentrations were higher in each of the test SRB's than in the baseline SRB's within six weeks of harvesting. By the end of the summer (10 weeks following harvesting) chlorophyll a concentrations were significantly higher in each of the harvested test basins than in the baseline SRB's.

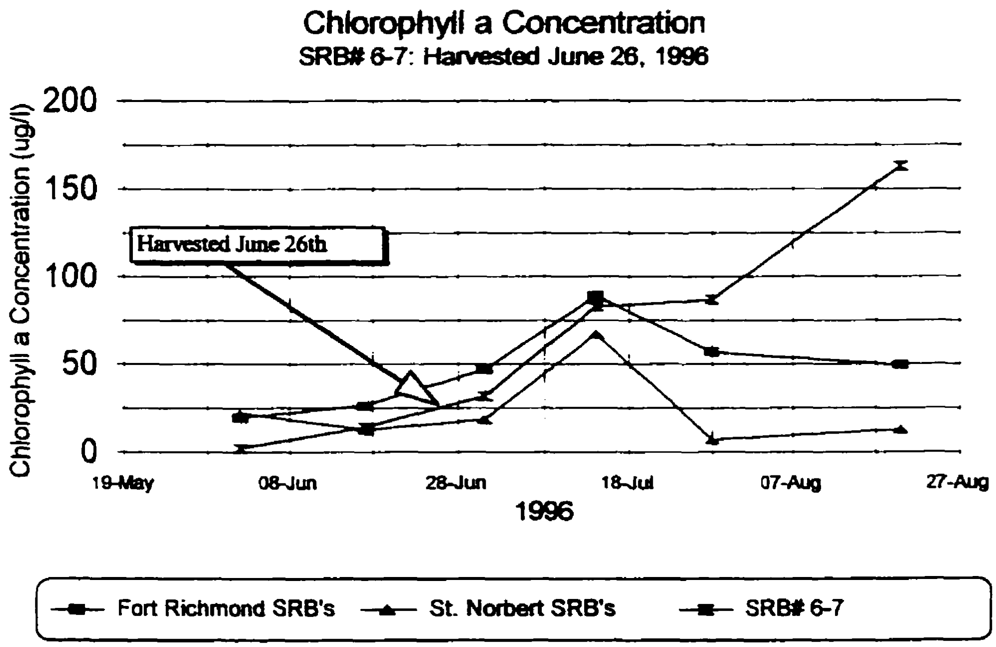


Figure 1

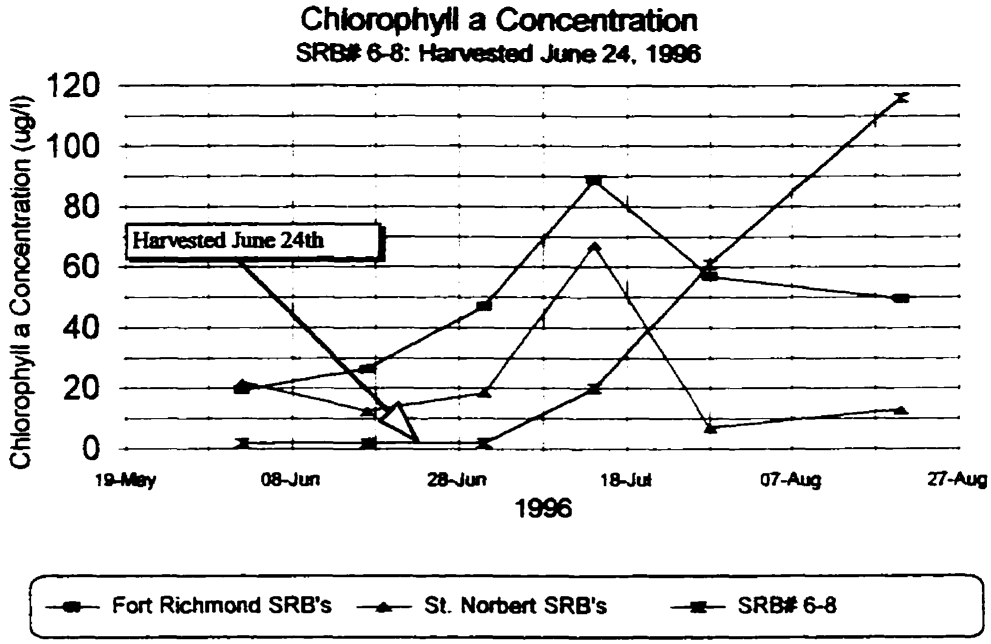


Figure 2

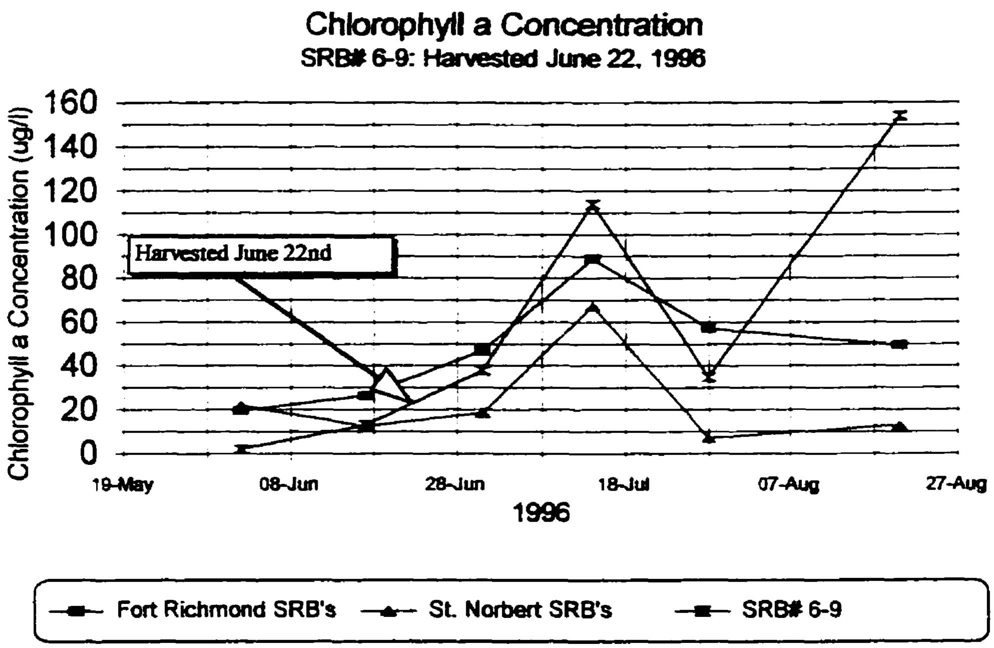


Figure 3

In order to establish a statistically relevant measure of the central tendency of chlorophyll a concentration, a finite rate analysis was deemed most appropriate (Krebs, 1985). For convenience we will define the following notation:

Y_0 = pre-harvested chlorophyll a concentration

Y_1 = post-harvested chlorophyll a concentration

Y_2 = final chlorophyll a concentration

Table 1 summarizes chlorophyll a concentrations observed in the 1996 study basins and presents a finite rate analysis of this data.

Test SRB #	Y_0 (ug/l)	Y_1 (ug/l)	Y_2 (ug/l)	Y_1/Y_0	Y_2/Y_0	$\ln(Y_1/Y_0)$	$\ln(Y_2/Y_0)$
6-7	14	32	163	2.29	11.64	0.83	2.45
6-8	2	2	116	1.00	58.00	0.00	4.06
6-9	13	38	154	2.92	11.85	1.07	2.47
Mean				2.07	27.16	0.63	3.00
exp (Mean)						1.88	20.00
Baseline SRB System	Y_0 (ug/l)	Y_1 (ug/l)	Y_2 (ug/l)	Y_1/Y_0	Y_2/Y_0	$\ln(Y_1/Y_0)$	$\ln(Y_2/Y_0)$
Fort Richmond Baseline SRB's	22 31	58 36	46 53	2.64 1.16	2.09 1.71	0.97 0.15	0.74 0.54
St. Norbert Baseline SRB's	14 11	16 21	11 15	1.14 1.91	0.79 1.36	0.13 0.65	- 0.24 0.31
Mean				1.71	1.48	0.47	0.34
exp (Mean)						1.61	1.40

Table 1: Finite Analysis of Seasonal Change in 1996 Chlorophyll a Concentrations

Table 1 reveals that during the 1996 harvesting program, the increase in chlorophyll a concentrations was greater in the test SRB's, than the baseline SRB's shortly after harvesting activities. An 88% increase in the geometric mean of chlorophyll a concentration change within the test SRB's was observed immediately following harvesting. This compares to an increase in the geometric mean of the change in baseline SRB's chlorophyll a concentration of 61% during the same period. Final 1996 readings indicated a seasonal increase in the geometric mean of the change between preharvested and final chlorophyll a concentrations of 2000%. This compared to an increase of 40% in the geometric mean of the change in baseline SRB's chlorophyll a concentration over the same time period. The final three chlorophyll a readings in SRB's 6-7, 6-8, and 6-9 demonstrated an upward trend in chlorophyll a concentrations while the baseline SRB's demonstrated a downward trend in chlorophyll a.

Results of the 1995 chlorophyll a analysis of harvested SRB's are presented in Figures # 4 to 6. The chlorophyll a analysis of SRB's 3-2, 3-3, and 3-4 provided similar feedback in terms of the impact of harvesting activities on chlorophyll a concentrations. In each of these test basins, a substantial increase in chlorophyll a concentration was observed in the June 28th samples, which represent the first analysis following harvesting activities. During this same period, the change in the chlorophyll a concentration in the baseline SRB's was mixed. A finite rate analysis of the long and short term changes in chlorophyll a concentrations for both harvested and baseline SRB's is presented in Table 2.

Test SRB #	Y_0 (ug/l)	Y_1 (ug/l)	Y_2 (ug/l)	Y_1/Y_0	Y_2/Y_0	$\ln(Y_1/Y_0)$	$\ln(Y_2/Y_0)$
3-2	17	143	55	8.41	3.24	2.13	1.18
3-3	27	80	114	2.96	4.22	1.09	1.44
3-4	3	58	106	19.33	35.33	2.96	3.56
Mean				10.23	14.26	2.06	2.06
exp (Mean)						7.85	7.85
Baseline SRB System	Y_0 (ug/l)	Y_1 (ug/l)	Y_2 (ug/l)	Y_1/Y_0	Y_2/Y_0	$\ln(Y_1/Y_0)$	$\ln(Y_2/Y_0)$
Fort Richmond	155	103	2	0.66	0.01	- 0.42	- 4.61
Baseline SRB's	116	94	9	0.81	0.08	- 0.21	- 2.53
St. Norbert Baseline	2	8	56	4.00	28.00	1.39	3.33
SRB's	11	142	48	12.91	4.36	2.56	1.47
Mean				4.60	8.11	0.83	- 2.34
exp (Mean)						2.29	0.10

Table 2: Finite Analysis of Seasonal Change in 1995 Chlorophyll a Concentrations

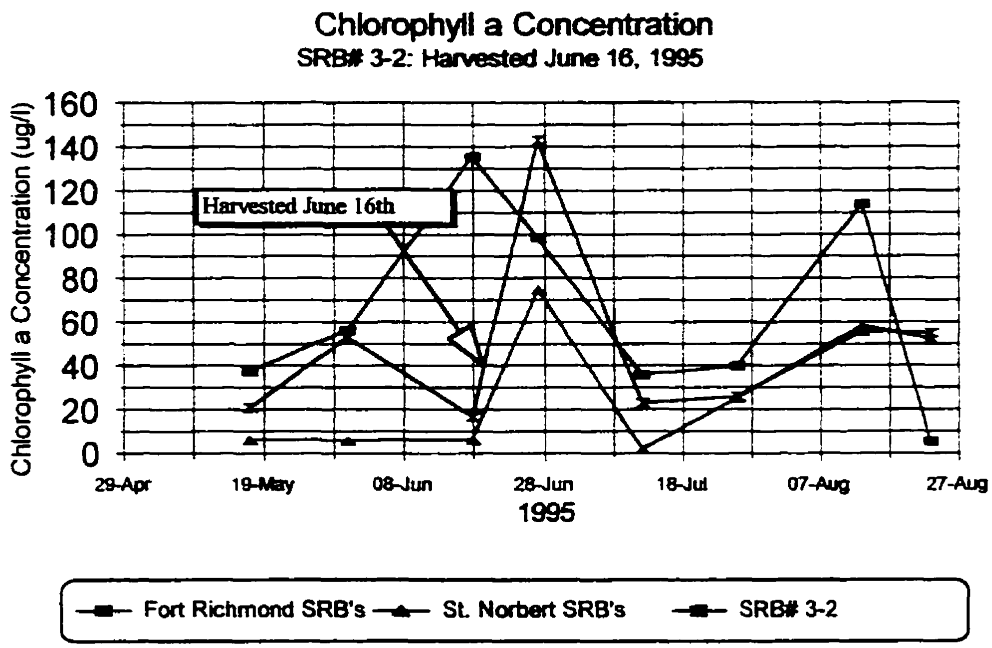


Figure 4

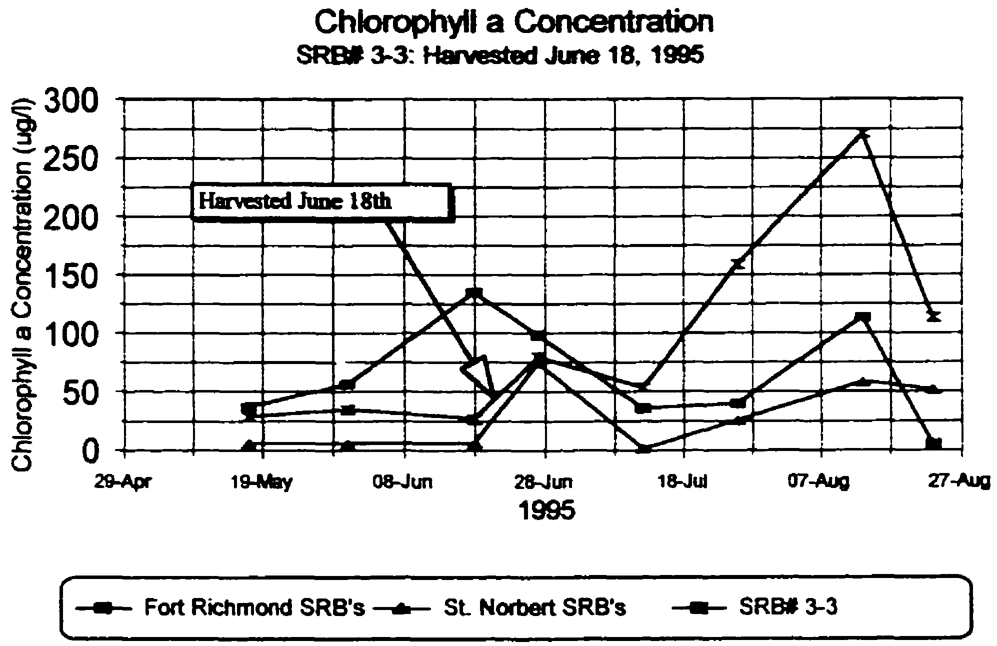


Figure 5

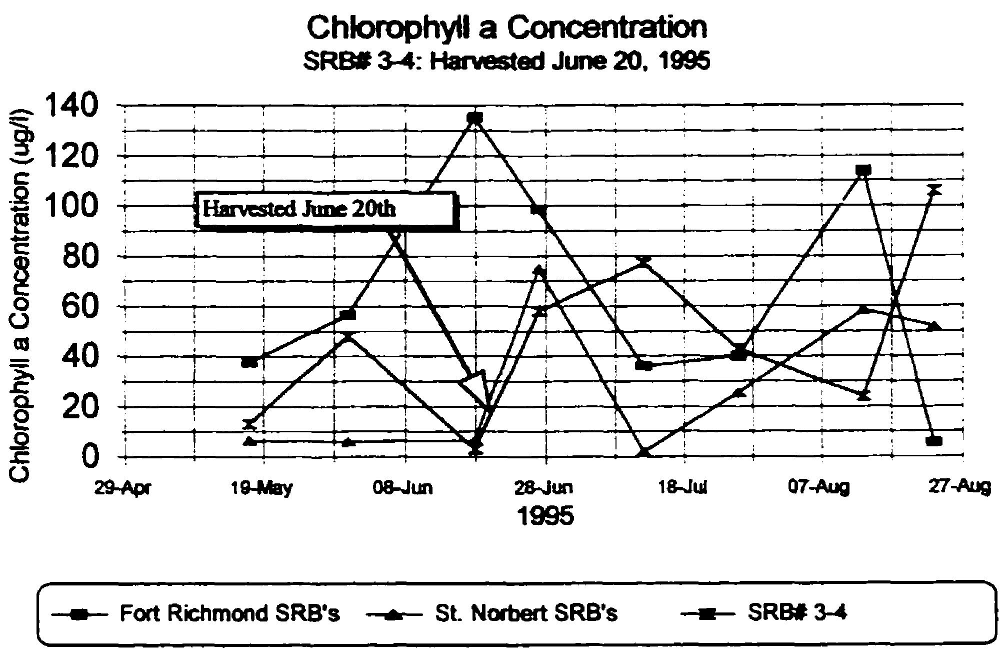


Figure 6

Table 2 depicts substantial increases in chlorophyll a concentrations occurring within harvested basins. The 1995 results are consistent with the data collected in 1996 and presented in Table 1. Shortly after harvesting activities, the increase in the geometric mean of the change in chlorophyll a concentrations within the 1995 test SRB's was 785%. This compares to an increase in the geometric mean of the change in baseline SRB chlorophyll a concentrations of 229%. By the end of the summer, the 1995 seasonal increase in the geometric mean of the change between the preharvested and final chlorophyll a concentrations was 785%. This compared to an increase in the geometric mean of the change in chlorophyll a concentrations within nonharvested basins of 10%, over the same time period.

Similar to the 1996 experience, beyond the June 28th testing date, chlorophyll a concentrations in the harvested basins followed a typically upward trend, ultimately increasing to levels greater than in either of the baseline SRB systems. This compares to initial chlorophyll a test concentrations which had found the chlorophyll a concentrations of the test basins to be at approximately the median of the two baseline systems.

Three plausible explanations for the observed increases in chlorophyll a concentration are hypothesized. The first is that resuspension of benthic nutrients could be a possible cause. Nutrient analysis results presented in Tables 3 to 8 demonstrate that although harvesting had no observable impact upon nitrate-nitrogen concentrations, increases in total phosphorus and total kjeldahl nitrogen (TKN) were relatively high following harvesting when compared to baseline SRB's during the same period. As TKN represents both particulate and soluble nitrogen, and nitrate-nitrogen measures soluble nitrogen, an increase in TKN but not nitrate-nitrogen implies an increase in particulate nitrogen following harvesting, therefore supporting the resuspension hypothesis. Total phosphorus also represents particulate and soluble phosphorus, and therefore increases observed in total phosphorus readings also support resuspension.

SRB #	Pre-Harvesting Nitrate-Nitrogen (mg/l)	Post-Harvesting Nitrate-Nitrogen (mg/l)	Change in Nitrate-Nitrogen
3-2	0.04	0.04	0.0%
3-3	0.04	0.04	0.0%
3-4	0.04	0.04	0.0%
Fort Richmond Baseline SRB's	0.04	0.04	0.0%
St. Norbert Baseline SRB's	1.59	0.04	-97.5%

Table 3: 1995 Harvesting Influence on Nitrate-Nitrogen Concentrations

SRB #	Pre-Harvesting Nitrate-Nitrogen (mg/l)	Post-Harvesting Nitrate-Nitrogen (mg/l)	Change in Nitrate-Nitrogen
6-7	0.04	0.14	250%
6-8	0.07	0.04	-42.9%
6-9	0.04	0.04	0.0%
Fort Richmond Baseline SRB's	0.06	0.04	-33.3%
St. Norbert Baseline SRB's	0.04	0.28	600%

Table 4: 1996 Harvesting Influence on Nitrate-Nitrogen Concentrations

SRB #	Pre-Harvesting Total Kjeldahl Nitrogen (mg/l)	Post-Harvesting Total Kjeldahl Nitrogen (mg/l)	Change in Total Kjeldahl Nitrogen
3-2	1.41	1.61	14.2%
3-3	1.83	1.97	7.7%
3-4	1.19	2.23	87.4%
Fort Richmond Baseline SRB's	2.50	1.11	-55.6%
St. Norbert Baseline SRB's	3.65	1.09	-70.1%

Table 5: 1995 Harvesting Influence on Total Kjeldahl Nitrogen Concentrations

SRB #	Pre-Harvesting Total Kjeldahl Nitrogen (mg/l)	Post-Harvesting Total Kjeldahl Nitrogen (mg/l)	Change in Total Kjeldahl Nitrogen
6-7	0.75	2.29	205%
6-8	0.28	1.18	321%
6-9	0.41	3.11	659%
Fort Richmond Baseline SRB's	1.07	2.92	172.9%
St. Norbert Baseline SRB's	1.13	2.31	104.4%

Table 6: 1996 Harvesting Influence on Total Kjeldahl Nitrogen Concentrations

SRB #	Pre-Harvesting Total Phosphorus (mg/l)	Post-Harvesting Total Phosphorus (mg/l)	Change in Total Phosphorus
3-2	0.08	0.32	300%
3-3	0.13	0.51	292%
3-4	0.04	0.11	175%
Fort Richmond Baseline SRB's	0.21	0.06	-71.4%
St. Norbert Baseline SRB's	0.24	0.06	-75.0%

Table 7: 1995 Harvesting Influence on Total Phosphorus Concentrations

SRB #	Pre-Harvesting Total Phosphorus (mg/l)	Post-Harvesting Total Phosphorus (mg/l)	Change in Total Phosphorus
6-7	0.07	0.25	257%
6-8	0.09	0.16	77.7%
6-9	0.11	0.18	63.6%
Fort Richmond Baseline SRB's	0.05	0.23	360%
St. Norbert Baseline SRB's	0.13	0.44	238%

Table 8: 1996 Harvesting Influence on Total Phosphorus Concentrations

The second explanation for the increase in chlorophyll a concentrations following harvesting is that the resuspension of seeds or other particulate matter during harvesting could stimulate germination of aquatic vegetation in the SRB and thus increasing chlorophyll a and dissolved oxygen concentrations. Although variable, dissolved oxygen (D.O.) concentrations of 10 mg/l are typical of harvested SRB's. D.O. profiles within the water column typically display higher concentrations near the surface and lower concentration nearer to the bottom. Surface and bottom concentrations of 11.5 mg/l and 8.5 mg/l respectively are typical of a Winnipeg SRB D.O. profile (Scales, 1993; Scales, 1994). These high concentrations of D.O. result in the presence of the most oxidized form of nitrogen, nitrate-nitrogen. Nitrate-nitrogen production could be in a state of dynamic equilibrium with the uptake of the soluble nutrient. This equilibrium could in part explain the neutral impact harvesting appeared to have upon nitrate-nitrogen concentrations within the test SRB's. Despite this, as phosphorus remains the governing nutrient for the proliferation of aquatic vegetation, the increase observed in total phosphorus following harvesting most probably results in the increase also observed in chlorophyll a concentrations.

The third explanation for the increases in observed chlorophyll a concentrations is that as biomass is removed by the harvester, weed and algae growth accelerates with the corresponding reduction in competition for available nutrients and sunlight. As phyloplankton and macrophyte masses increase to fill the void of vegetation created from harvesting, chlorophyll a concentrations would increase.

In an effort to assess the plausibility of first two above mentioned hypotheses, both turbidity and transparency levels in the harvested SRB's were measured and compared to the baseline hydraulic systems. Increases in turbidity levels and decreasing transparency distances following harvesting would imply a reduction water clarity and therefore support resuspension theories. Water clarity in SRB's is however, influenced by other external events and factors such as the contribution of additional runoff and sediments following rainfall. As such, consideration of turbidity and transparency data should be undertaken with some reservation.

Figures # 7 to 12 compare turbidity levels in harvested SRB's to the baseline SRB systems over the course of the summer months in 1995 and 1996. This analysis indicated that substantial increases in turbidity were normally measured following harvesting activities, and typically stabilized thereafter. These results compared to the baseline SRB's typically showing no change in turbidity during the same period of time, immediately after harvesting in the test basins. Table 9 indicates the variation in 1996 turbidity levels of both harvested and baseline SRB's during the same time periods, which corresponded to pre and post harvesting conditions in the test SRB's.

SRB #	Pre-Harvesting Turbidity (ntu)	Post-Harvesting Turbidity (ntu)	Post-Harvest Change in Turbidity	Final Turbidity (ntu)	Seasonal Change in Turbidity
6-7	2.6	6.5	150.0%	8.3	219.2%
6-8	2.9	1.8	- 37.9%	27.0	831.0%
6-9	2.8	11.0	292.9%	7.0	150.0%
Fort Richmond Baseline SRB's	14.8	12.0	- 18.9%	22.0	48.6%
St. Norbert Baseline SRB's	7.9	9.2	16.5%	3.1	- 60.8%

Table 9: Seasonal Change in 1996 Turbidities

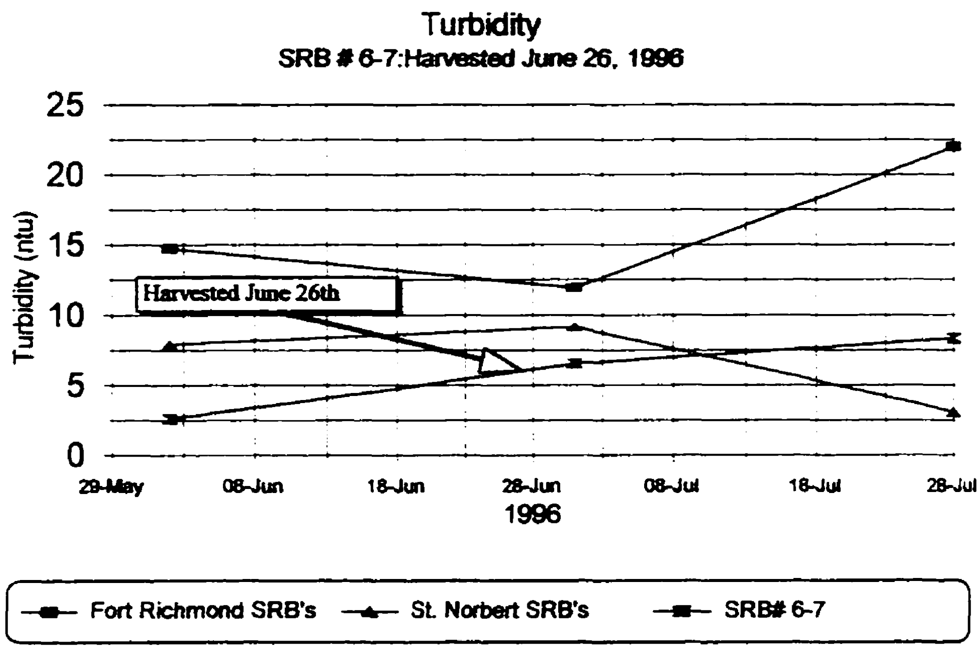


Figure 7

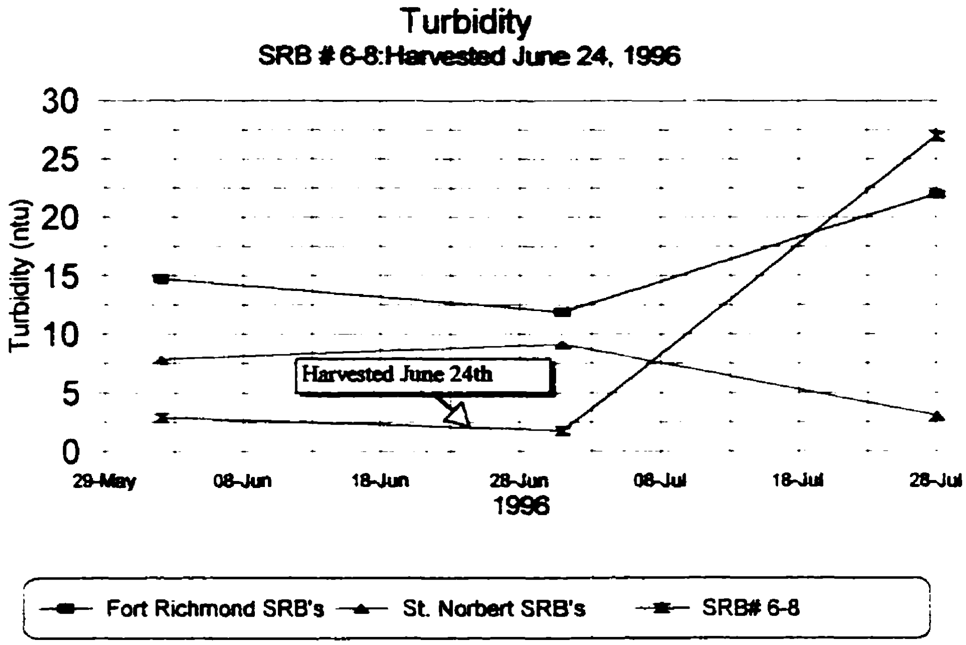


Figure 8

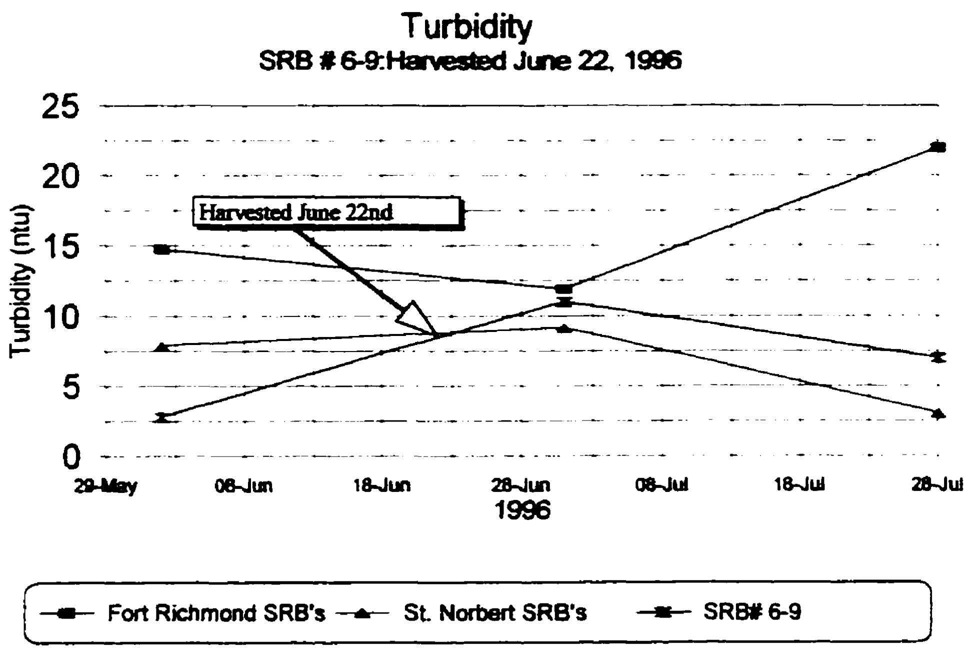


Figure 9

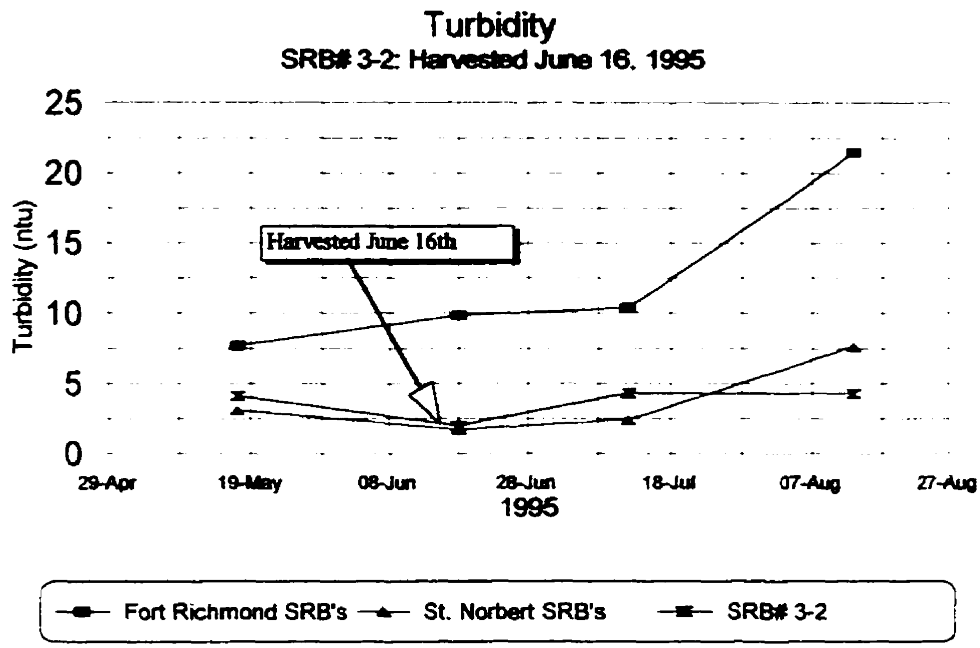


Figure 10

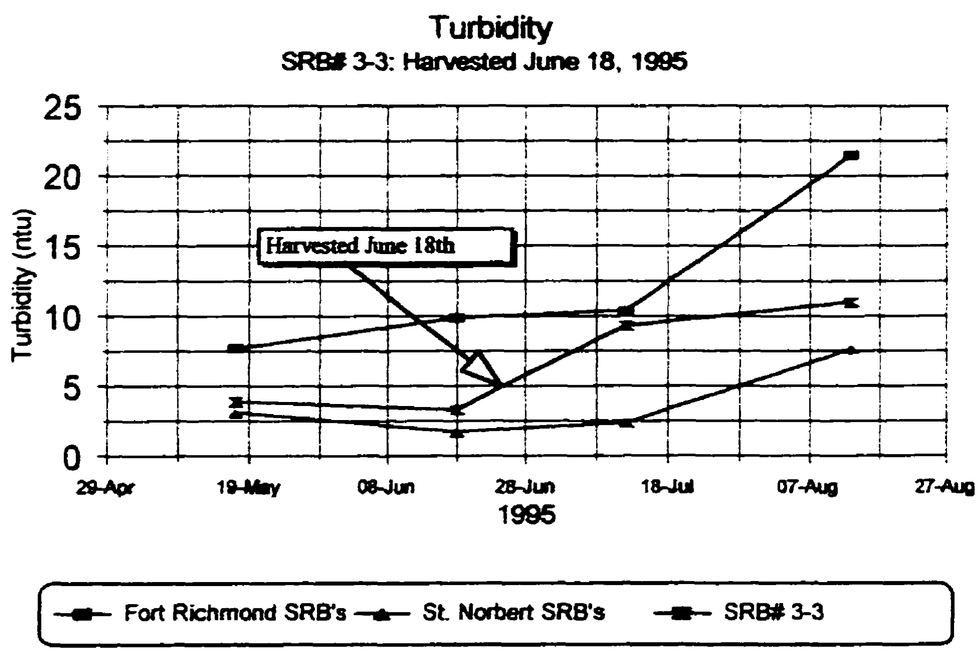


Figure 11

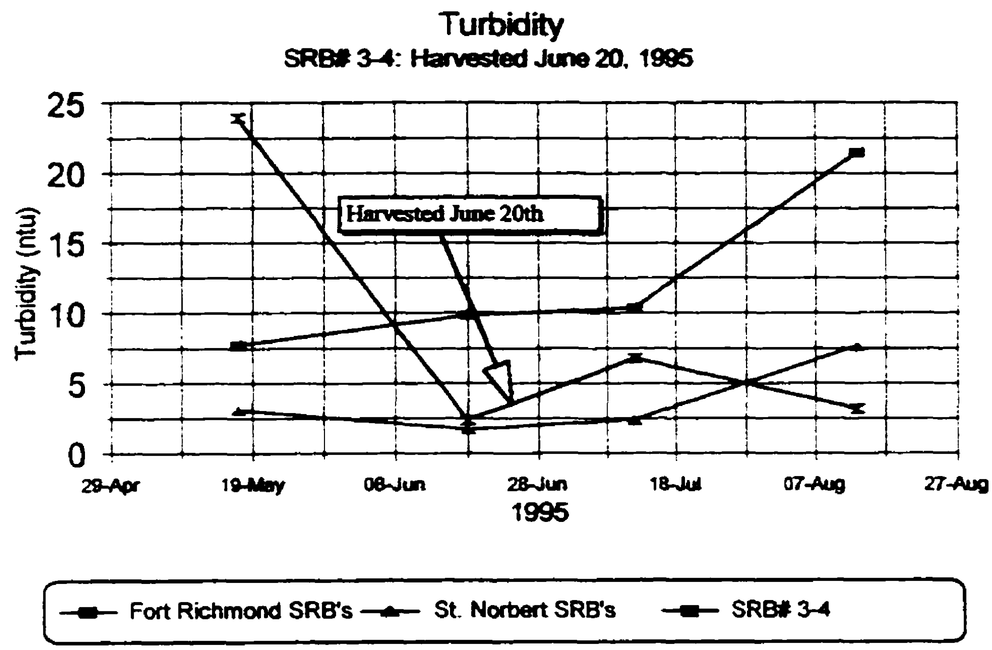


Figure 12

The change in SRB turbidity presented in Table 9 reveals that following the 1996 harvesting program, turbidity increases in the harvested SRB's was between -38% and 293%, with a mean increase of 135%. This compares to turbidity increases of -19% and 17%, for a mean increase of -1% in the baseline SRB's. By the end of the summer, the 1996 seasonal increase in the preharvested and final turbidity levels ranged from 150% to 831%, with a mean increase of 400%. This compared to increases of -61% and 49% in baseline SRB's over the same time period, for a mean increase in turbidity levels of -6% for nonharvested basins.

Table 10 implies a similar trend in turbidity levels immediately following harvesting activities during the 1995 SRB harvesting program, however final analysis indicated a greater increase in turbidity in baseline SRB's than those which underwent harvesting.

SRB #	Pre-Harvesting Turbidity (ntu)	Post-Harvesting Turbidity (ntu)	Post-Harvest Change in Turbidity	Final Turbidity (ntu)	Seasonal Change in Turbidity
3-2	2.0	4.3	115.0%	4.3	115.0%
3-3	3.3	9.3	181.8%	11.0	233.3%
3-4	2.4	6.8	183.3%	3.2	33.3%
Fort Richmond Baseline SRB's	9.9	10.4	5.1%	21.5	117.2%
St. Norbert Baseline SRB's	1.7	2.4	41.2%	7.7	352.9%

Table 10: Seasonal Change in 1995 Turbidities

The turbidity changes depicted in Table 10 indicate that shortly after harvesting activities, increases in turbidity levels within the 1995 test SRB's ranged from 115% to 183%, with a mean change of 160%. This compares to turbidity increases of 5% and 41% during the same time period within the baseline SRB's, for a mean increase of 23%. By the end of the summer, the 1995 seasonal increase between the pre-harvested and final turbidity readings ranged from 33% to 233%, with a mean increase of 127%. This compared to increases of 117% and 353% in baseline SRB's over the same time period, for a mean increase in turbidity levels of 235% for nonharvested basins.

Although the relative increase in final turbidity readings differed between the 1995 and 1996 test programs, the importance of these final readings is nominal, as resuspended material had

8 to 10 weeks to settle between harvesting activities and the final sampling of the season. As such, any impact of harvesting upon turbidity would have largely dissipated during this time period. Of more significance is the greater increase in turbidity levels experience by both 1995 and 1996 test SRB's immediately following harvesting activities. This consistency supports the hypothesis of resuspension of benthic materials following harvesting.

Further to the investigation of the resuspension hypotheses, transparency of the harvested basins was also compared to that of the baseline hydraulic systems. Figures # 13 to 18 demonstrate a trend towards lower, or reduced transparency in the test basins following harvesting compared to baseline conditions during the same period.

SRB #	Pre-Harvesting Transparency (m)	Post-Harvesting Transparency (m)	Post-Harvest Change in Transparency	Final Transparency (m)	Seasonal Change in Transparency
6-7	0.4	0.2	-50.0 %	0.3	-25.0 %
6-8	0.8	0.9	12.5 %	0.3	-62.5 %
6-9	0.4	0.2	-50.0 %	0.3	-25.0 %
Fort Richmond Baseline SRB's	0.25	0.15	-40.0 %	0.4	60.0 %
St. Norbert Baseline SRB's	0.2	0.2	0.0 %	0.8	300.0 %

Table 11: Seasonal Change In 1996 Transparencies

Table 11 indicates that during the 1996 harvesting program, the decrease in transparency was greater in the test SRB's, than the baseline SRB's shortly after harvesting activities. The change in transparency distances ranged from -50 % to 13% of preharvesting transparency in the test SRB's immediately following harvesting, with a mean change of -29%. This compares to transparency distance increases of 0% and -40%, for a mean increase of -20% in the baseline SRB's during the same period. Final 1996 transparency readings indicate a seasonal increase between preharvested and final transparency values ranging from -62.5% to -25%, with a mean increase of -38%. This compared to increases of 60% and 300% in baseline SRB's over the same time period, for a mean increase in transparency of 180% for nonharvested basins.

SRB #	Pre-Harvesting Transparency (m)	Post-Harvesting Transparency (m)	Post-Harvest Change in Transparency	Final Transparency (m)	Seasonal Change in Transparency
3-2	1.0	0.2	-80.0 %	0.4	-60.0 %
3-3	0.6	0.6	0.0 %	0.1	-83.3 %
3-4	0.8	0.4	-50.0 %	0.3	-62.5 %
Fort Richmond Baseline SRB's	0.1	0.25	150.0 %	0.1	0.0 %
St. Norbert Baseline SRB's	0.6	0.75	25.0 %	0.1	-83.3 %

Table 12: Seasonal Change In 1995 Transparencies

The decrease in transparencies within the test SRB's is further demonstrated in Table 12, which compares the change in 1995 harvested SRB transparencies to baseline SRB's transparencies during the same time period. The change in transparency distances ranged from -80% to 0% of preharvesting transparency in the test SRB's immediately following harvesting, with a mean change of -43%. Comparatively, transparency distance increases of 25% and 150%, or a mean increase of 88% in the baseline SRB's were experienced during the same period. 1995 transparency readings indicate a seasonal increase between preharvested and final transparency values ranging from -60% to -83%, with a mean increase of -69%. This compared to seasonal transparency increases of 0% and -83% in baseline SRB's over the same time period, for a mean increase in transparency of -42% for nonharvested basins. This tendency towards a lower transparency subsequent to harvesting further supports the hypothesis that harvesting turbulence results in resuspension of benthic substrate, thereby encouraging a renewed proliferation of submerged macrophytes and algae.

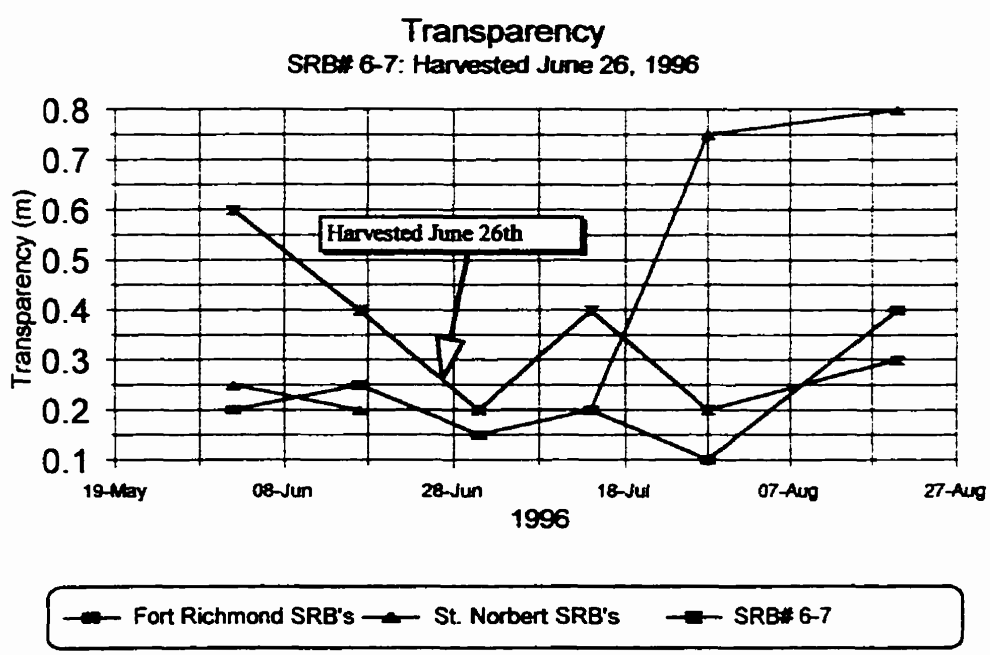


Figure 13

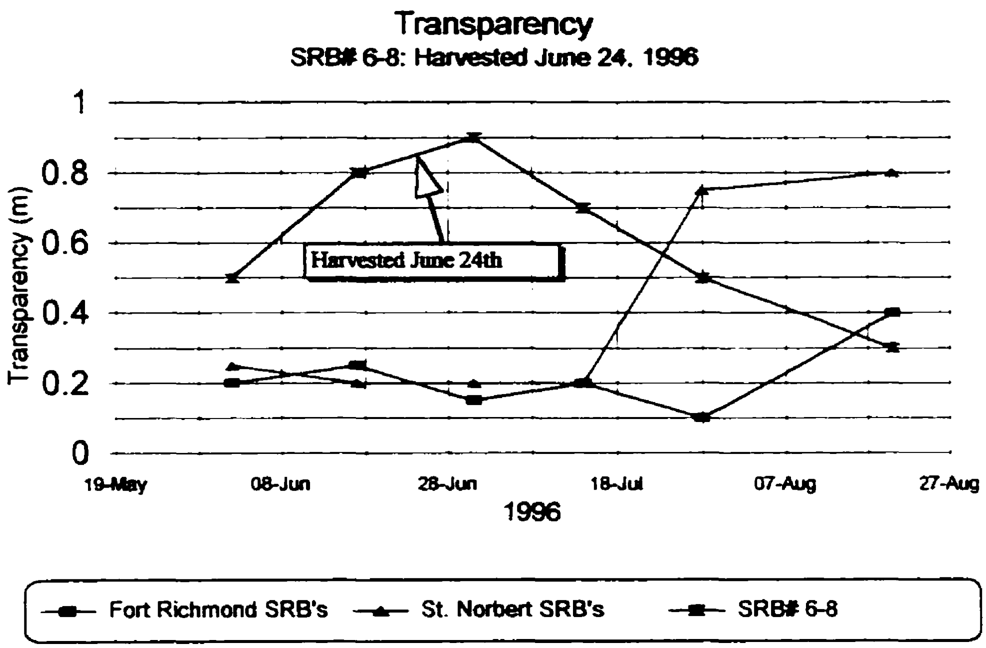


Figure 14

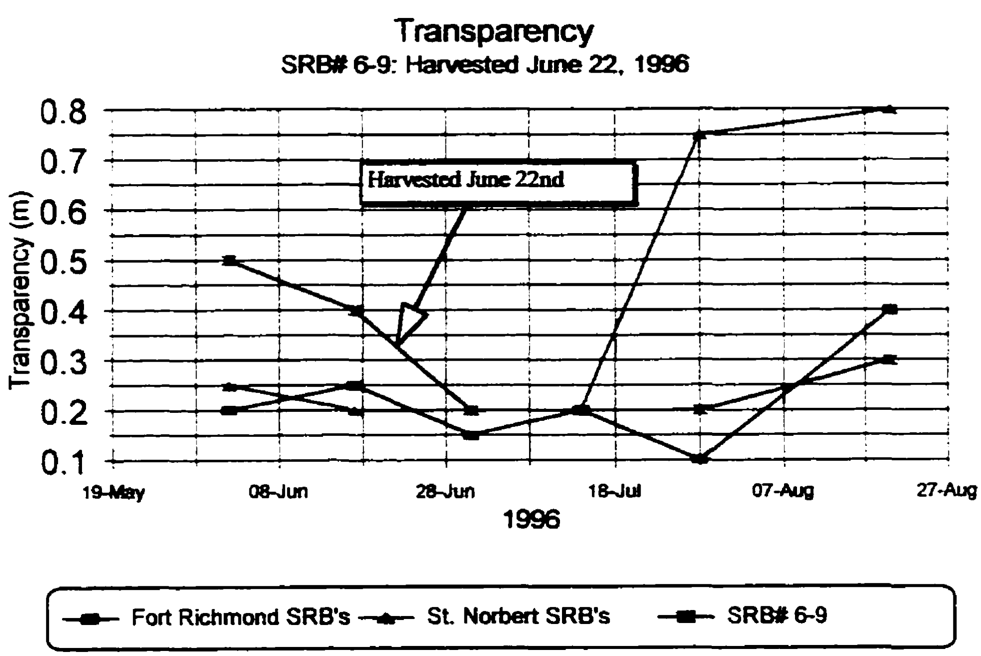


Figure 15

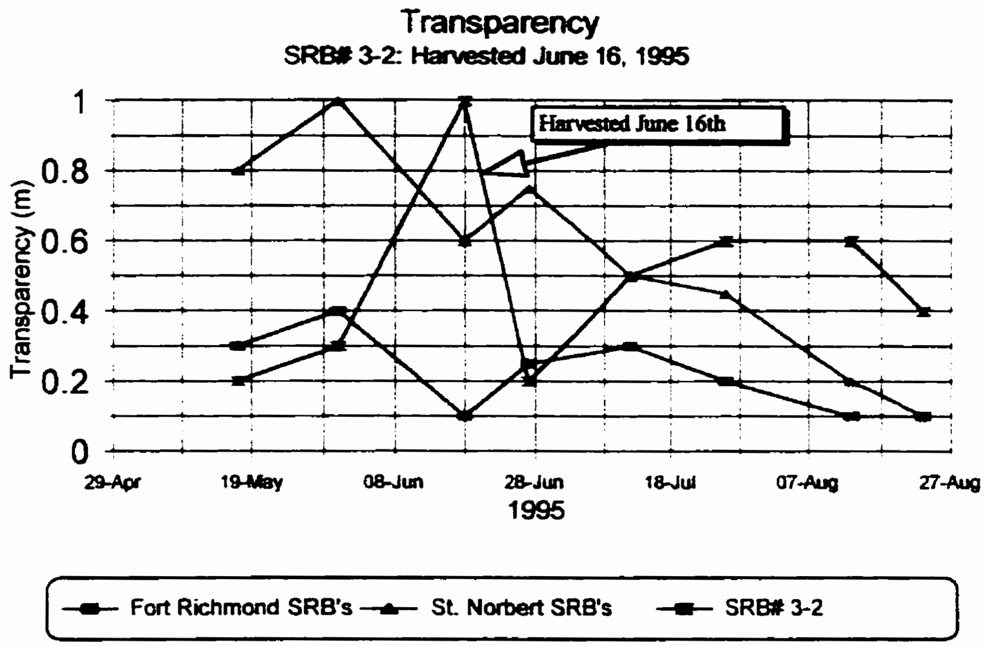


Figure 16

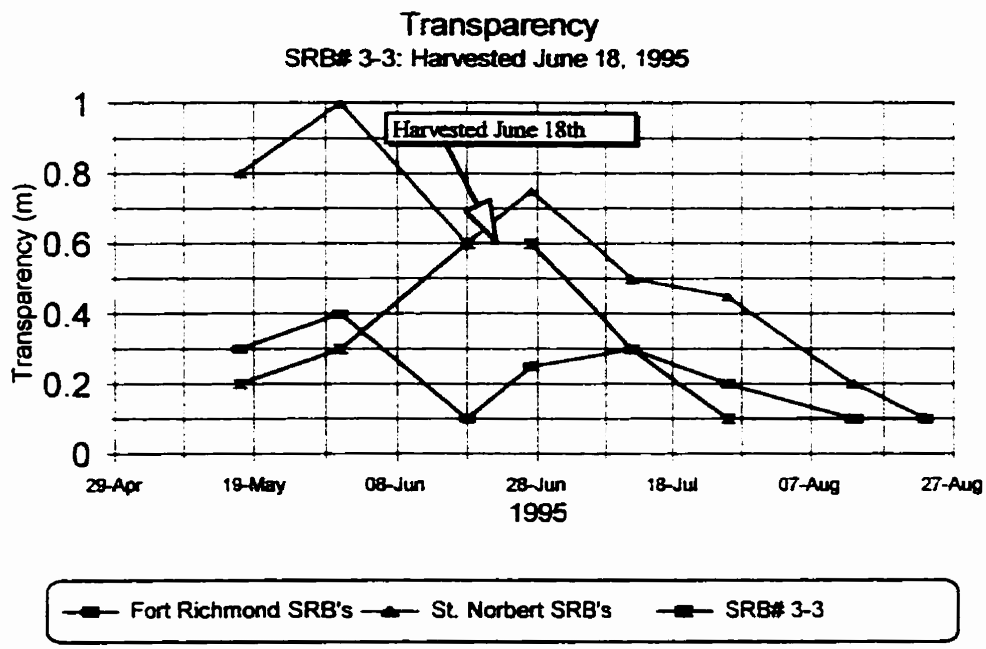


Figure 17

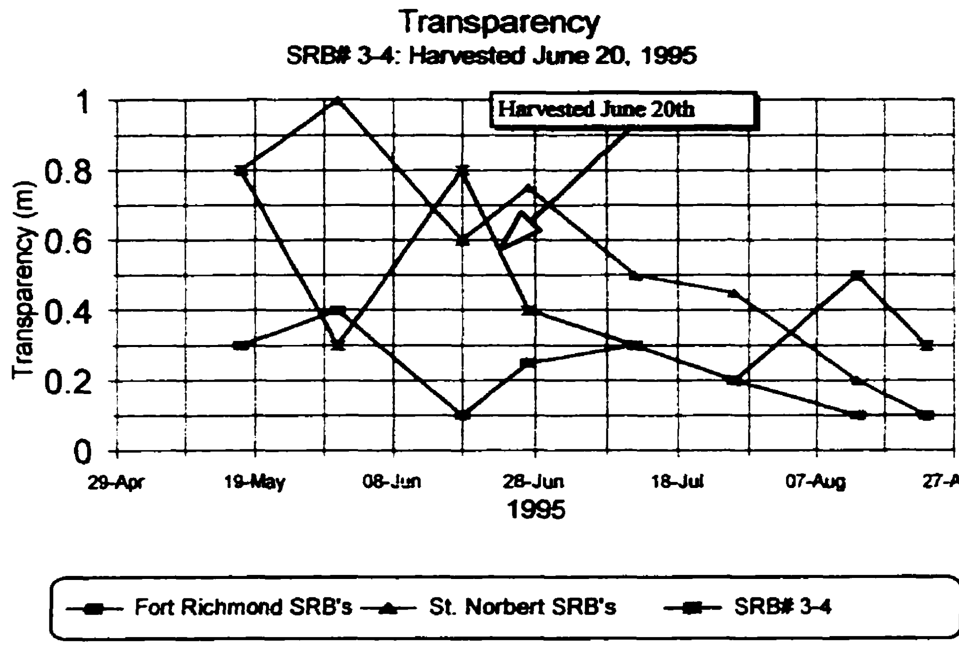


Figure 18

pH was also recorded, and the results are in presented in Figures # 19 to 24. pH analysis and trending was undertaken as it was hypothesized that any resuspend matter which may be causing the increase in turbidity may contain a significant CO_2 component and therefore result in a pH increase within the water column. pH fluctuations have been related to algal productivity and pH values have been found to be directly proportional to chlorophyll a concentrations (Prepas and Babin, 1989). As such, concerns that the proliferation of algae blooms may in fact be being encouraged by pH increases resulting from the turbulence of harvesting operations existed. This analysis, although cursory and based upon limited data, implied a trend towards higher pH following harvesting in the test basins when compared to the baseline SRB's.

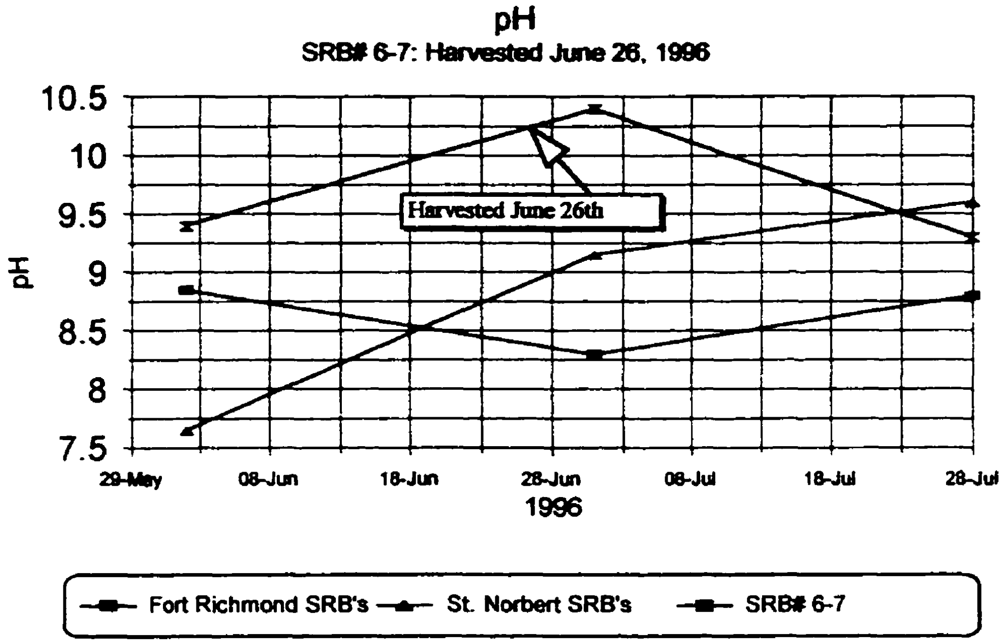


Figure 19

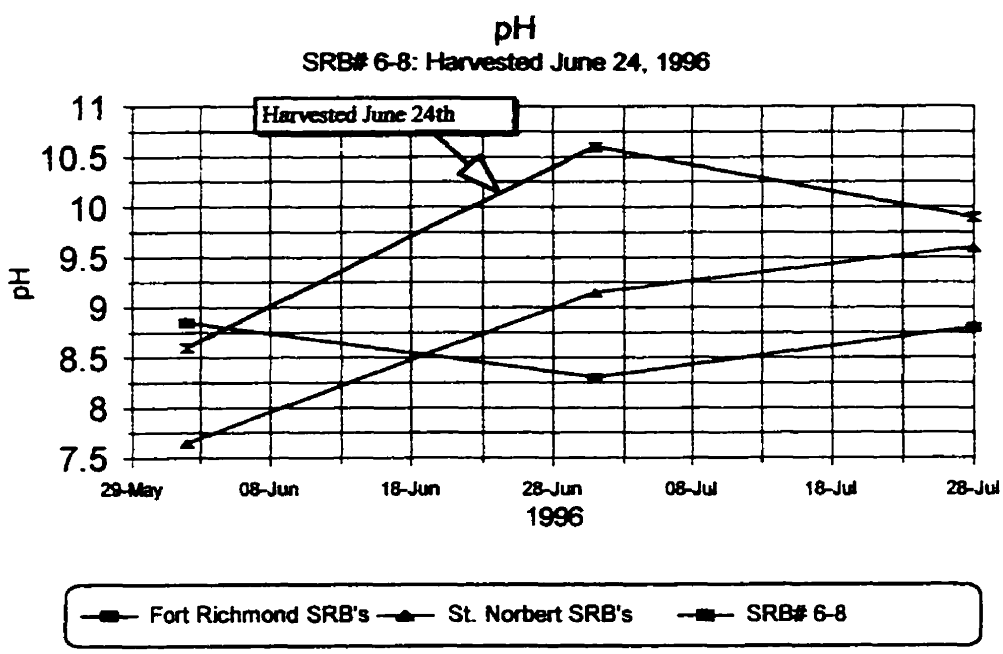


Figure 20

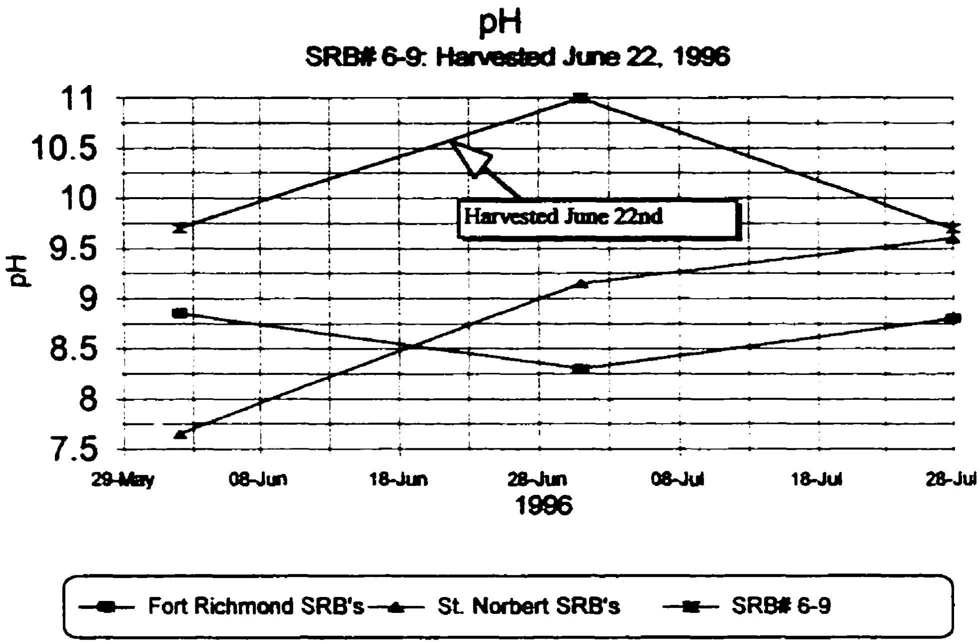


Figure 21

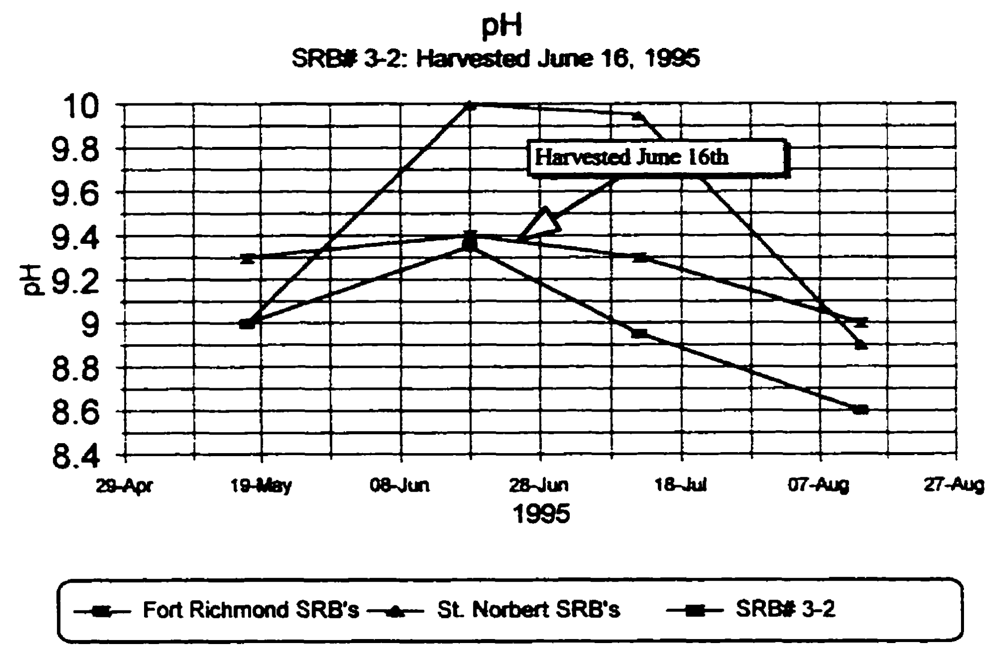
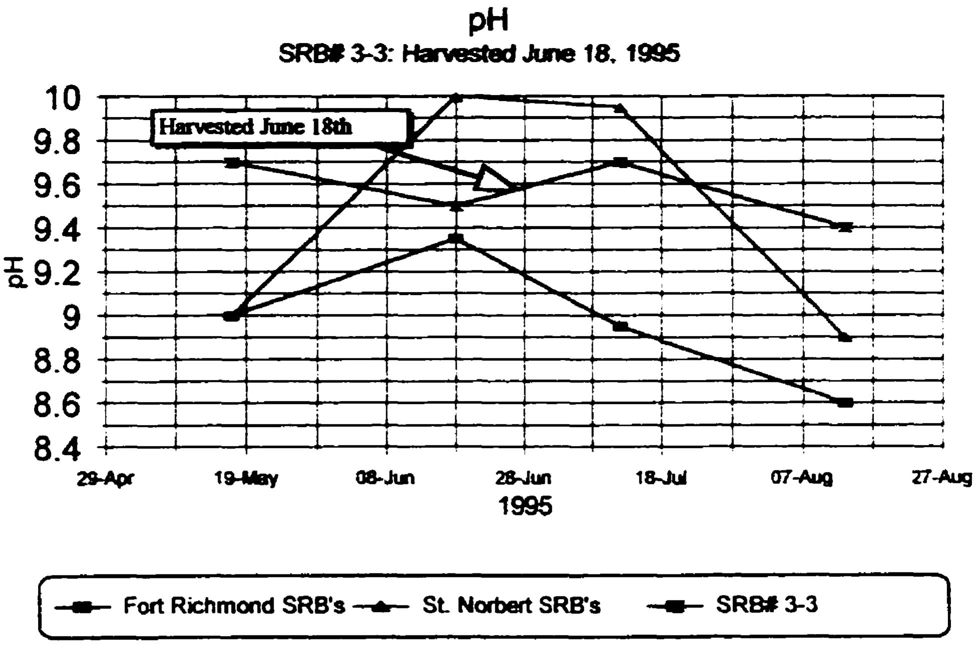


Figure 22



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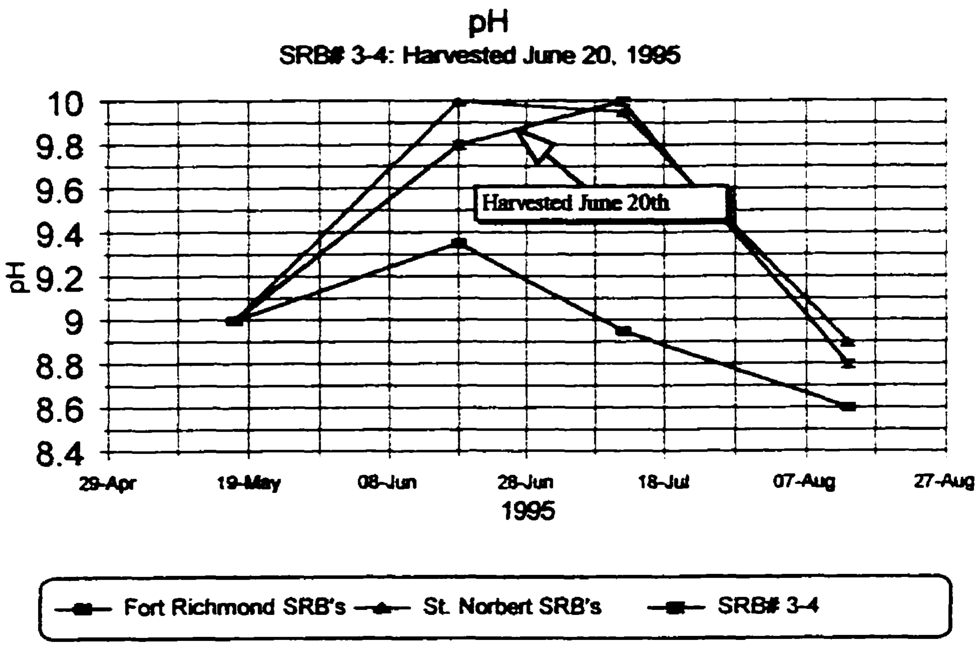


Figure 24

5.3 Effectiveness of Herbicide Applications

During August of 1996, Karmex DF was applied to the entire surface of SRB's 2-4 and 5-18, and to a 3 m wide perimeter on SRB 5-15. Reglone A was applied to the entire surface area of SRB 4-10, and to a 3 m wide perimeter surrounding SRB 5-21. The intent of this approach was to compare the effectiveness of each herbicide to baseline conditions, harvesting, and to each other. Chlorophyll a and transparency data collected on the herbicide treated basins is presented in Figures # 25 to 32.

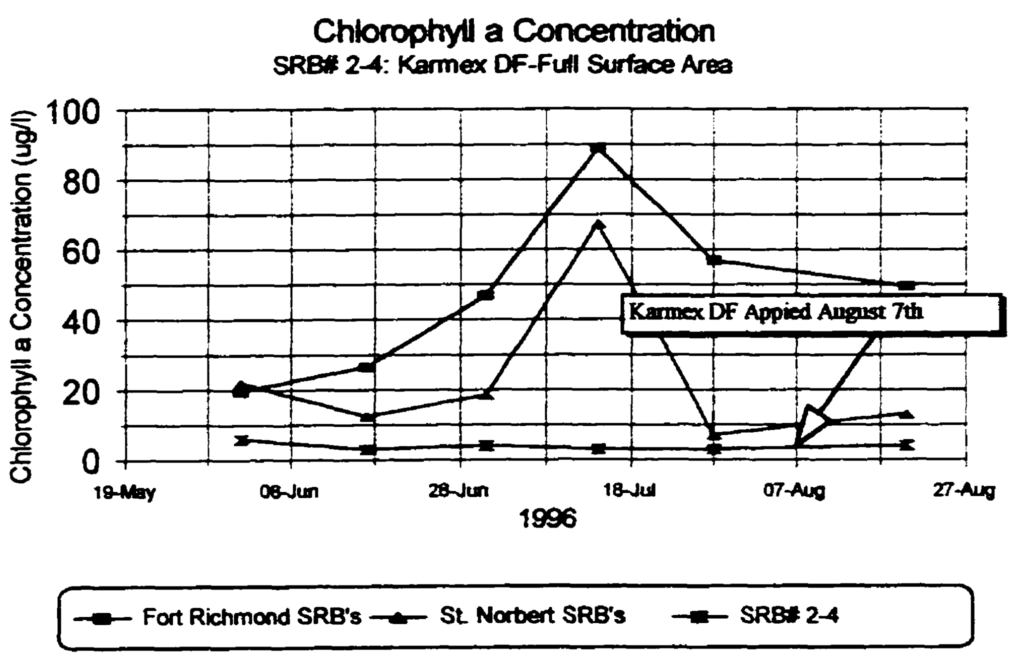


Figure 25

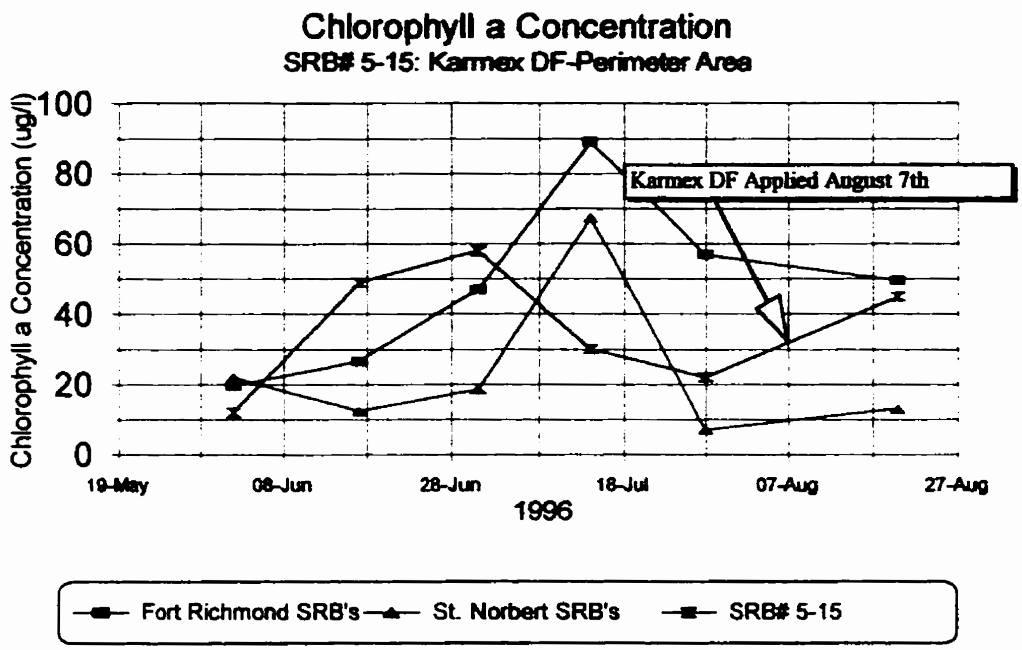


Figure 26

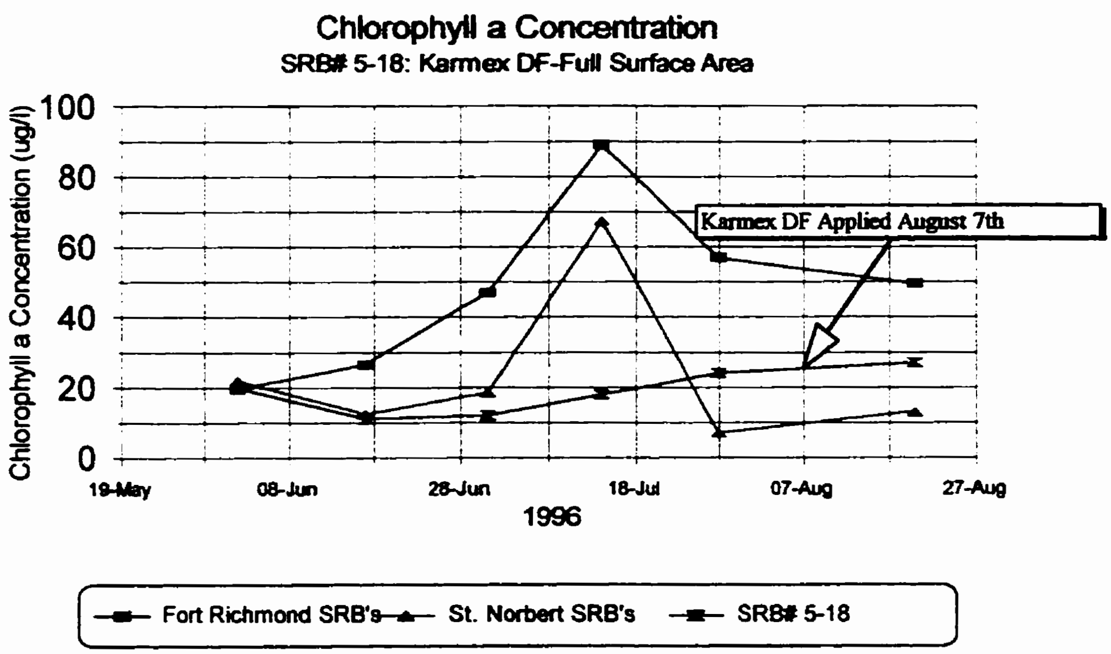
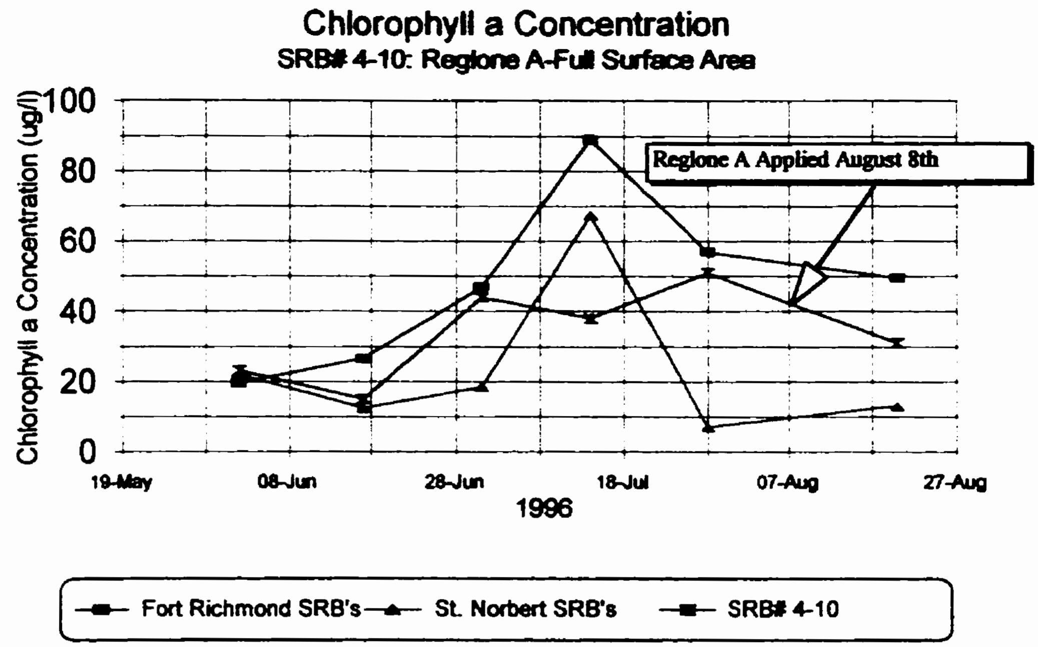


Figure 27



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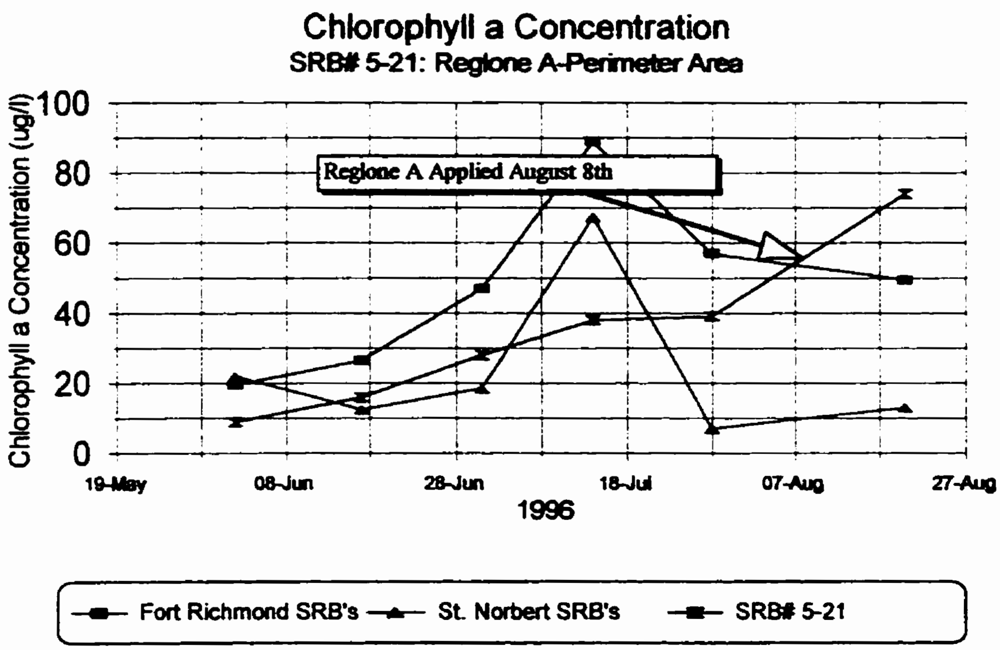

Figure 29

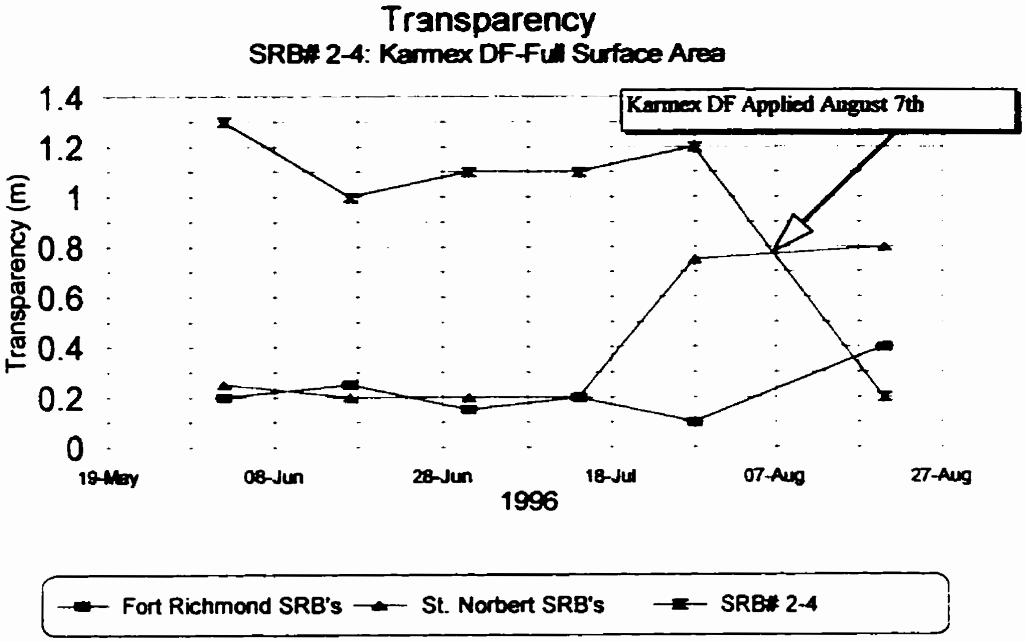

Figure 30

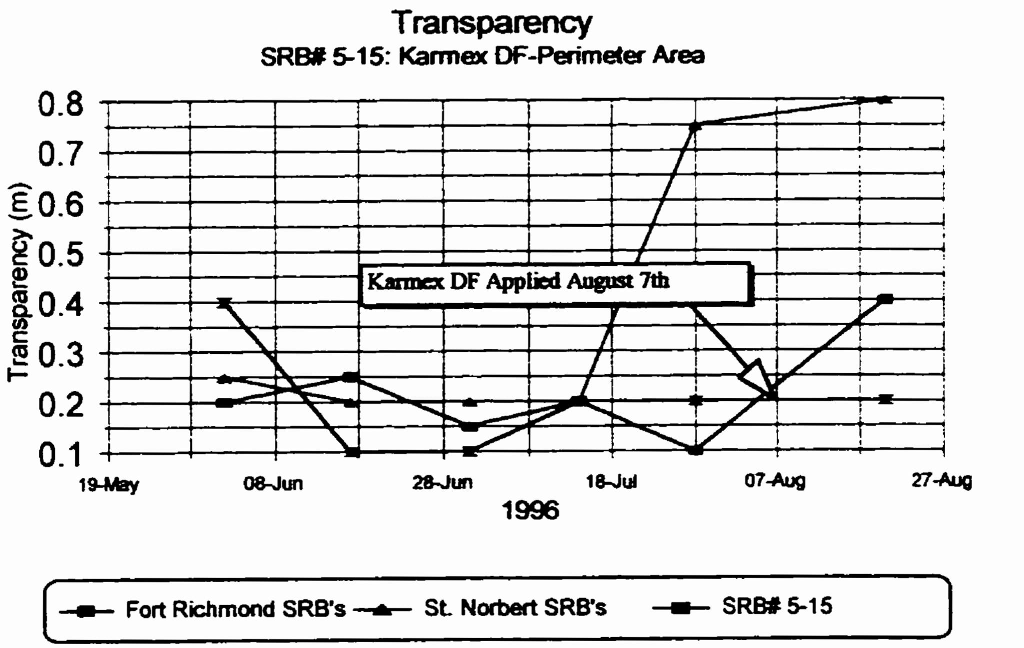

Figure 31

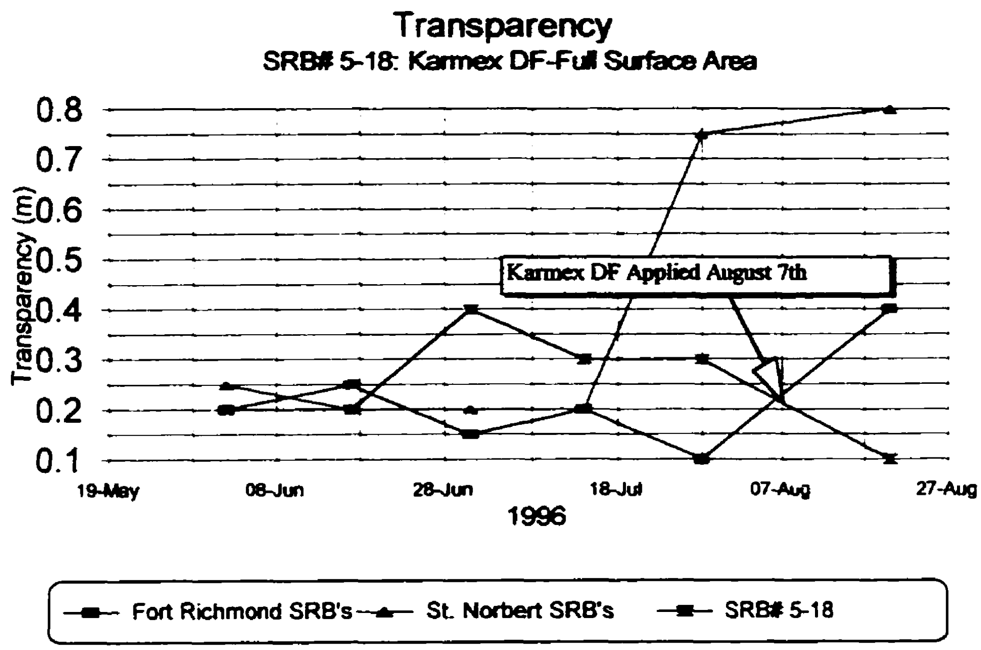

Figure 32

Perimeter and surface area applications were compared qualitatively and quantitatively as the majority of resident's concerns appear to pertain to the immediate shoreline of their properties. Furthermore, weed and algae proliferation tends to decrease in concentration at greater depths (UMA Engineering Ltd., 1992), thus resulting in a reduction in benefits associated with treating further from shore. Following application, chlorophyll a concentration and transparency were also measured and compared to the Fort Richmond and St. Norbert baseline SRB system's. The raw data collected during this analysis is presented in Appendix III.

The late application only permitted the collection of one data point following treatment, however early indications were that full surface treatment provided a more effective means of reducing chlorophyll a concentrations. The limited transparency data implied a decrease in the clarity of the SRB's following herbicide application.

Although quantitatively inconclusive due to the limited volume of data collected, qualitative field observations indicated that both the Reglone A and Karmex DF applications were effective means of controlling weed and algae. Following application of both herbicides, a dramatic reduction in weed and algae concentrations was observed in the test basins, and resident's complaints regarding the condition of the treated SRB's ceased. As such, herbicides were again applied to nine SRB's during June of 1997 to further monitor their effectiveness. 1997 applications of Reglone A included SRB's 4-10, 5-15, and 5-21. Karmex DF applications included SRB's 2-2, 2-4, 4-6, 4-9, 5-16, and 5-18.

Herbicide application in 1997 was applied at the earlier June date in an effort to achieve benefits for longer periods of summer, in addition to providing larger quantitative data sets to study the impact of the herbicide treatment. Unfortunately resource limitations did not permit water quality analysis of the SRB's in 1997, and a more detailed quantitative assessment could not be undertaken. Despite this, qualitative field observations once again indicated that herbicide treatment of SRB's provided substantial reductions in weed and algae concentrations and increase in water clarity. Residents' complaints also ended in 1997 on SRB's treated with Reglone A and Karmex DF following application. Photographs of

Karmex DF test SRB 2-4 were taken prior to and subsequent to herbicide application and are presented in Appendix IV. These observations were further supported by a dramatic decrease in resident complaints on the herbicide treated basins during the summer of 1997.

In an effort to acquire a greater understanding of the effectiveness, mechanism, and residency time of Karmex DF and Reglone A treatments, further water quality analysis of SRB's was recommended for 1998. During June 1998 application of Reglone A occurred in SRB's 4-2, 4-10, 4-6, 5-9, 5-15, and 5-21, and Karmex DF was applied to 2-4, 3-10, 4-9, 5-16, 5-18 in an effort to treat the SRB's prior to germination of weeds and algae. Water quality data collection and analysis was also undertaken by the University of Manitoba in 1998, and final results are forthcoming.

Qualitative and quantitative evidence again suggested the both herbicides were highly effective in controlling weed and algae, although Reglone A demonstrated a more limited effectiveness when a high suspended solids concentration was present and photo penetration was therefore reduced. The promise demonstrated by these products resulted in additional applications to SRB's 6-6, 6-12, 6-13, and 6-20 as water quality complaints were received by residents over the course of the summer of 1998.

6.0 CONCLUSIONS

Developers' promotion and marketing of Stormwater Retention Basins (SRB's) as clear, pristine lakes as opposed to naturalizing wetlands or drainage structures has resulted in a perception and service expectation by residents which is difficult, if not impossible to satisfy. Conventional methods of aquatic vegetation management which have traditionally been applied in an attempt to satisfy residents' expectations have either been chemical or mechanical in nature. Historically effective chemical means employed by the City of Winnipeg have included the use of copper sulfate based algicides, or simazine based sterilents. Commercially available algicides and sterilents included Cutrine and Princep Nine-T respectively. These products had proven to be an excellent complement to mechanical removal methods prior to the recent ban of their use in SRB's.

Aquatic vegetation harvesting provides an environmentally sound means of short term weed control in large, geometrically simple SRB's. Macrophyte control is undertaken without the introduction of chemical herbicides or sterilents, and provides the additional benefit of physically removing the fixed nutrients stored within the biomass, from the water column. Despite this, operational limitations which exist with aquatic weed harvesting include constraints due to SRB size, SRB geometry, and environmental conditions. In addition to being operationally limited by periods of rainfall, wind may also complicate operations, and in some instances result in unacceptable performance which may even prove aesthetically counterproductive. Furthermore, the aquatic weed harvester's inability to operate in waters shallower 0.4 m further results in a three to five meter wide unharvested band around the SRB perimeter. This unharvestable shoreline growth represents the most visible and sensitive area of the SRB to residents as it is immediately adjacent to their properties. In addition to the unsightly and odorous nature of the shoreline growth, it further acts as a net for floating debris and additional vegetation cut, but not collected, by the harvester. These problems, in addition to the rapid proliferation of weed and algae concentrations observed subsequent to harvesting, resulted in questions with respect to the impact mechanical harvesting has upon chlorophyll a concentrations in SRB's.

Water quality analysis indicated that subsequent to harvesting activities, no reduction in chlorophyll a concentration was observed in any of the test basins, despite the removal of aquatic vegetation during harvesting, in either 1995 or 1996. In 1996, chlorophyll a concentrations actually increased substantially in two of the three test basins immediately following harvesting operations. Furthermore, 1996 post harvesting chlorophyll a concentrations were highest in each of the test basins within six weeks of harvesting. By the end of the summer (10 weeks following harvesting) chlorophyll a concentrations were significantly higher in each of the 1996 harvested test basins than in the baseline SRB's.

The chlorophyll a analysis of SRB's harvested in 1995 provided similar feedback in terms of the impact of harvesting activities on chlorophyll a concentrations. In each of these test basins, a substantial increase in chlorophyll a concentration was observed following harvesting activities. During this same period, the change in the chlorophyll a concentration in the baseline SRB's was mixed.

Three explanations for the observed increase chlorophyll a concentrations following harvesting were hypothesized. These were resuspension of benthic nutrients during harvesting, resuspension of seeds or other particulate matter during harvesting, and acceleration of replacement growth resulting from a reduction in competition for available nutrients and sunlight.

Increases in turbidity levels and decreasing transparency distances following harvesting implied a reduction water clarity and therefore supported resuspension theories. Water clarity in SRB's is however, influenced by other external events and factors such as the contribution of additional runoff and sediments following rainfall. As such, consideration of turbidity and transparency data should be undertaken with some reservation.

In concert with the resuspension hypotheses, it was recognized that the proliferation of algae blooms may in fact be being encouraged by pH increases resulting from the turbulence of harvesting operations. As such, analysis to investigate the impact of harvesting upon pH was undertaken. Although cursory and based upon limited data, the results implied a trend towards higher pH subsequent to harvesting in the test basins when compared to the baseline SRB's.

In response to the difficulties experienced with conventional weed and algae control methods, a number of emerging technologies and methods, at various stages of commercial availability, were investigated. These methods include alternative herbicides for application, SRB aeration, lime treatment, barley straw application, and introduction of sterilized grass carp. In addition, a shoreline raking program was also conducted and reviewed on an experimental basis.

The shoreline raking pilot program proved ineffective and impractical due to a high labor component and low vegetation removal rates. Logistical and coordination failures further hampered the program, often resulting in results counterproductive to the intended objective of improved aesthetics.

Review of alternative emerging weed and algae control methods indicated that the most promising methods available to supplement or replace the aquatic weed harvesting program included sterilized grass carp and the use of the commercially available herbicides Reglone A and Karmex DF. As sterilized grass carp were not yet commercially available, only pilot studies of Reglone A and Karmex DF were undertaken.

Investigation into the effectiveness of the herbicides Karmex DF and Reglone A indicated that both provided promise as competitive means for weed and algae control, and each could prove to be important supplements to, or replacements for, conventional harvesting practices. Although the late application of these herbicides in 1996 permitted the collection of limited data following treatment, early indications were that both herbicides provided an effective means of reducing chlorophyll a concentrations. The limited transparency data implied a decrease in the clarity of the SRB's following herbicide application.

Although quantitatively inconclusive due to the limited volume of data collected, qualitative field observations indicated that both the Reglone A and Karmex DF applications were effective means of controlling weed and algae. As such, herbicides were again applied to SRB's during June of 1997 and 1998 to further monitor and evaluate their effectiveness. Although 1997 and 1998 water quality data was unavailable, qualitative observations and a reduction in residents' complaints were positive indicators of their performance.

7.0 RECOMMENDATIONS

In an effort to redefine residents' expectations for Stormwater Retention Basins (SRB's), public education initiatives should be pursued, and developers should be approach with respect to their marketing of SRB's, and the expectations they promote to potential homeowners and residents. Marketing SRB's as naturalizing wetlands and educating the public as to the natural evolution of these basins may result in a different consumer market group for SRB frontage, but the ultimate result would be a population whose expectations are more practically satisfied through the naturalization of SRB's. Therefore both operational cost savings, and environmental benefits of SRB naturalization could be more easily realized through the development of wetland perceptions by residents.

Review of alternative weed control measure should continue, coupled with ongoing data collection and analysis of both conventional and pilot programs against baseline conditions in an effort to realize more efficient, effective, and environmentally benign methods of weed and algae management. Investigation into the feasibility of a sterilized grass carp pilot program should also be undertaken, with implementation and study when possible.

Further study of more basins with intensified data collection and analysis of SRB water quality immediately before and following harvesting activities is also recommended as a means to better identify the effectiveness and impact of mechanical harvesting and applying herbicide to SRB's. Parameters for analysis could be expanded to include testing for the germination of sago pond weed and algae.

Examination of the impact of Karmex DF and Reglone A applications on Chlorophyll a production in SRB's should continue to be investigated as means for control of weed and algae proliferation in SRB's. Furthermore, more detailed economic comparison of treatment alternatives such as herbicide applications and mechanical harvesting should be undertaken, with the water quality data being further compared against water quality in untreated SRB systems.

Diquat and diuron concentrations should also be monitored subsequent to application of Karmex DF and Reglone A in a effort to establish the duration of their residency within the SRB's. Some basins having had herbicide treatment in earlier years should be disqualified from herbicide application for one year or more and monitored in an effort to establish the duration of weed and algae control following application of each herbicide. Establishment of staggered herbicide application, whereby SRB's are treated every second or third year would result in a tremendous increase in the cost effectiveness of herbicide treatments should diquat or diuron residency time prove sufficient.

The City of Winnipeg's weed and algae control program should shift its operational emphasis from harvesting to a more balanced program of conventional aquatic weed harvesting and herbicide controls. Review of the impact, both economically and in terms of customer satisfaction, of the move away from harvesting and towards herbicide applications should be monitored. Ultimately, an optimal balance of weed and algae management alternatives should be established, likely consisting of a combination of a variety of control alternatives.

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APPENDIX I: Aquatic Weed Harvester Photographs and Design Specification Drawings

Figure A-1: Aquatic Weed Harvester Operating with Cutting Head

Figure A-2: Aquatic Weed Harvester Operating with Cultivating Head

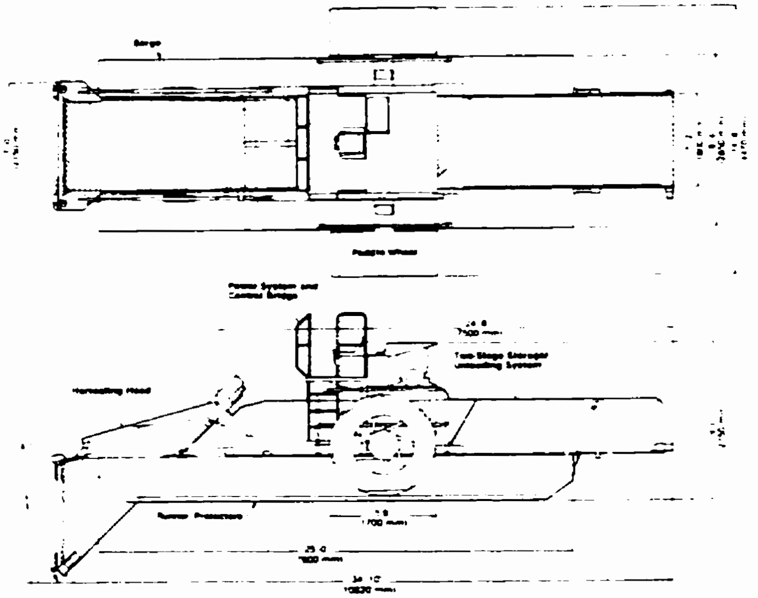
Figure A-3: Front View of Aquatic Weed Harvester

Figure A-4: Side View of Aquatic Weed Harvester

Figure A-5: Aquatic Weed Harvester Cutting Head Close Up

Figure A-6: Aquatic Weed Harvester

H7-400 Aquatic Plant Harvester



Specifications:

Dimensions:	Length Overall	34' 10" (10 620 mm)
	Shipping Width	9' 4" (2850 mm)
	Operating Width	14' 8" (4470 mm)
	Shipping Height	9' 0" (2750 mm)
	Operating Height	9' 5" (2870 mm)
	Weight	11 000 lbs (5000 kg)
	Shipping Height of Harvester on T400 Standard Trailer	11' 7" (3530 mm)
	Shipping Height of Harvester on TC400 Trailer Conveyor	11' 7" (3530 mm)
Flotation:	Barge Length	25' 0" (7600 mm)
	Barge Width	9' 4" (2850 mm)
	Barge Height	2' 2" (660 mm)
	Watertight Compartments	[illegible]
	Barge Bottom Protection	Pressure treated wood runners, polyethylene slider pads
	Harvester Draft, empty	10" (260 mm)
	Harvester Draft, with maximum load	1' 6" (460 mm)
Power System and Control Bridge:	Engine	4 cylinder, water cooled diesel 43 HP @ 2800 rpm (32 kW @ 2800 rpm)
	Hydraulic Pump	Variable volume, pressure compensated
	Hydraulic Reservoir	25 U.S. gallons (95 L)
	Fuel Tank	18 U.S. gallons (68 L)
	Operator's Seat	Adjustable
	Hydraulic Controls	Combination foot controls, fingertip manual levers
	Power System Controls	Full instrumentation
Harvesting Head:	Cutting Width	7' 0" (2150 mm)
	Cutting Depth	5' 0" (1500 mm)
	Horizontal Knives	Reciprocating stroke 4" (100 mm) wide, zinc plated
	Vertical Knives	Same as above, both sides
	Impact Absorption	Pivoted swing suspension
	Belting	Standard duty, galvanized
	Fastenings	Stainless steel
Two-Stage Storage Unloading System:	Length Overall	24' 5" (7500 mm)
	Width	5' 2" (1600 mm)
	Loading Height	3' 2" (950 mm)
	Maximum Volume	400 cubic feet (11.5 m³)
	Maximum Weight	7 000 lbs (3200 kg)
	Unloading Height	Hydraulically adjustable from 0 to 4' 6" (0 to 1400 mm)
	Unloading Time	30 seconds
	Belting	Standard duty, galvanized
	Fastenings	Stainless steel
Propulsion:	Dual Paddle Wheels	Easily removeable, Hydraulically driven, independently reversible
	Paddle Wheel Diameter	5' 6" (1700 mm)
	Paddle Wheel Width	2' 6" (760 mm)
	Paddle Wheel Speed	Variable in range 0-50 rpm
Anti-Corrosion System:	High Impact, Thermally Cured Epoxy	Fresh and salt water protection
	Color	High visibility safety orange

Specifications subject to change without notice

H7-400 Harvester Features:

1 Zinc plated, easily replaceable, 4" wide (100 mm) harvesting head knives deal more effectively than 3" wide (75 mm) knives with larger stem diameter aquatic plants such as rushes and cattails and allow the increased productivity, efficiency and storage capacity of the H7-400 harvester to be fully utilized. Knife wear is reduced by 33% and the plant diameter cutting range is increased by 30% which can translate into a significant productivity increase and a substantial reduction in the unit cost of harvesting.

2 The rear storage/unloading conveyor, which is hydraulically adjustable through a range of 0 to 4'-6" (0 to 1400 mm) provides valuable unloading flexibility where steep or restricted shore access exists.

3 Stainless steel type 18-8 fastenings provide corrosion protection in both fresh and salt water as does the multi-coat, thermally cured high visibility safety orange applied to a white blasted substrate.

Auxiliary Equipment:

Trailer, Trailer Conveyor, Shore Conveyor

Optional Equipment:

Electrically Operated Jib Crane, Operator's Sun/Rain Canopy, Heavy Duty Galvanized Belting Package, Standard Duty Stainless Steel Belting, Heavy Duty Stainless Steel Belting Package, Saltwater Package, Light Package, Oil Drip Pan, Standard Spare Parts Kit, Extended Spare Parts Kit, Paddle Wheel Guards

LAKESCAPE INTERNATIONAL

AQUARIUS SYSTEMS
A Division of D&D Products Inc

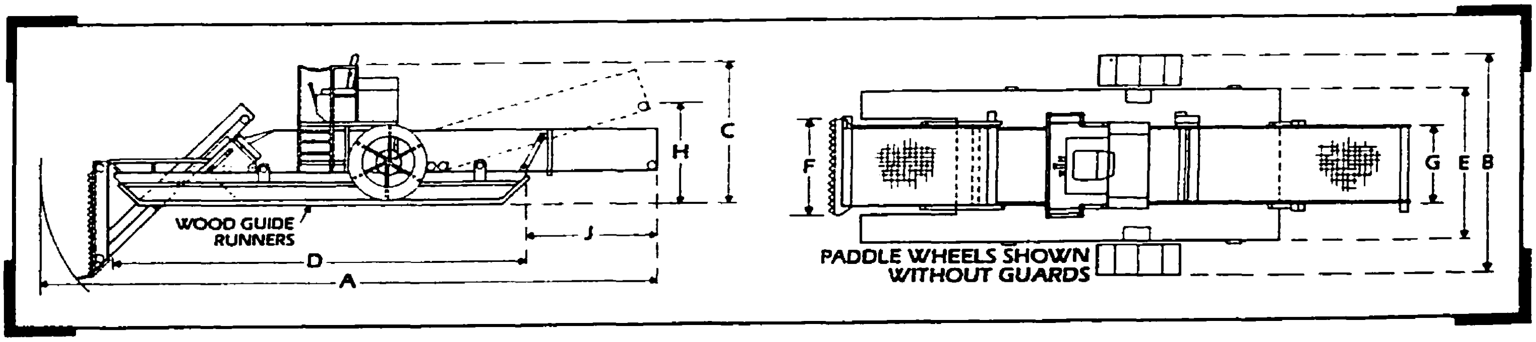
EH-SERIES FEATURES

- For added safety, paddle wheel guards are standard.
- Flexible break away springs on harvesting head absorb shocks and automatically reset.
- To aid in unloading plant material, discharge height is adjustable from 0 to 5 feet.
- Restricted shore access is more easily reached by the extra long discharge conveyor that stretches 6'-7" beyond the rear of barge.
- Two marine outboard fuel tanks are conveniently portable for easy refueling.
- Harvesters are equipped with the customer's choice of a gas or diesel engine.
- American standard 3" agricultural chrome plated cutter knives allow higher velocity operation, greater cutting surface, and are readily available at all farm implement dealers.
- Shear fingers of forged steel protect cutter teeth from damage.
- Wood runners covered with UHMW plastic slider pads protect barge bottom and guide harvester smoothly on and off of trailer.
- Excellent protection against corrosion is provided by thermally cured epoxy finish over white sand-blasted substrate.
- Lockable tool and battery box.
- Accessory equipment available includes: Trailer/Conveyors, Trailers, Shore conveyors and Transports. Custom options are also available to meet the customer needs.

EH-220 AQUATIC PLANT HARVESTER SPECIFICATIONS

DIMENSIONS:	(A)	Operating Length	31'-0"
	(B)	Operating Width	11'-10"
	(C)	Operating Height	7'-6"
		Shipping Length	31'-0"
		Shipping Width	8'-2"
		Shipping Height	7'-6"
		Height on Trailer	10'-1"
FLOTATION:	(D)	Barge Length	21'-0"
	(E)	Barge Width	8'-2"
		Barge Height	18½"
		Harvester Weight	6,500 lbs.
		Draft Empty	10"
		Draft Max. Load	15"
		Compartments	5
		Displacement	3.07" per ton
POWER PACK:		Engine	20 H.P. Optional gasoline or diesel
		Hydraulic Pump	Variable volume, pressure compensated
		Hydraulic Reservoir	18 gal. Visual site gauge Visual temperature gauge
		Fuel Tanks	2 Portable, 6 gallons each
CONTROL BRIDGE:		Hydraulic Controls	Manual levers
		Operator Seat	Adjustable
		Systems Control	Full instrumentation
		System Protection	Relief Valves
HARVESTING HEAD:	(F)	Cutting Width	5'
		Cutting Depth	5'
		Horizontal Knives	Reciprocating 3" stroke
		Vertical Knives	Reciprocating 3" stroke
		Shear Fingers	Horizontal-forged steel Vertical-formed steel
		Impact Absorption	Breakaway springs, automatic reset
		Conveyor Belting	1"x 1" Galvanized, standard
LOAD CONTAINER:		Length	22'-0"
	(G)	Width	4'-1"
		Height	2'-3"
		Storage (Volume)	200 cubic feet
		(Weight)	3,200 lbs.
		Unload Time	90 seconds
	(H)	Discharge Height	0-5'
	(J)	Discharge Distance	From rear of barge 6'-7"
		Conveyor Belting	1"x 1" Galvanized, standard
PROPULSION:		2 Paddle Wheels	Hydraulic drive, independently reversible
		Diameter & Width	48"x 18"
		Paddle Wheel R.P.M.	Variable 0-50
FASTENERS:		Stainless Steel	Throughout machine

SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE
Made in U.S.A.



APPENDIX II: Winnipeg Stormwater Retention Basin Locations

Table A-1: STORMWATER RETENTION BASIN LOCATIONS

BASIN NUMBER	BASIN LOCATION
2-2	Off Isbister Street north of Hamilton Avenue
2-3	South side of Lumsden between Galbraith Cr. And Kay Cr.
2-4	North of South Lake Drive
2-5	North of Whitfield Avenue in Omand's Creek Industrial Park
3-1	Southeast corner of King Edward Street and Selkirk Avenue
3-2	Northeast corner of King Edward Street and burrows Avenue
3-3	North of Burrows Avenue at Benbow Road
3-4	Northeast corner of Garton Avenue and Belton Street
3-5	Northwest of Red River Boulevard and Riverstone Road
3-6	North of Templeton Avenue and west of McPhillips Street behind City of Winnipeg District #3 maintenance yards
3-7	Extreme rear of Motorways property on Oak Point Highway. Accessible only through Motorways property
3-8	Mount Baker Drive east of Keewatin Street
3-9	Foxwarren Drive West of Ritchie Street
3-10	Amber Trails
4-1	Located in front of Gov't of Canada Regional Tax Data Centre. Corner of Lagimodiere Blvd. And Regent Avenue
4-2	Off Gateway Road north of Springfield Road (Bunn's Creek)
4-3	Not operational, cordite Ditch
4-4	Northeast Park Recreation Area
4-5	Northwest corner of Devonshire Drive and Clouston Drive
4-6	Southeast of Devonshire Drive and Kildonan Meadow Drive
4-7	Deep pond southwest Ravelston Avenue and C.N.R. Victoria Beach
4-8	Northeast Park (corner Lagimodiere and Springfield)
4-9	South of McMahon Place off McLellan Drive
4-10	North of Ragsdill Road between East Spring and West Spring Coves
4-11	East of Molson Street and south of Grassie Blvd.

BASIN NUMBER	BASIN LOCATION
5-1	West of Beghin Avenue at Paquin Road
5-2	East of Paquin Road
5-3	South of Camiel Sys. Street, east of Ray Marius Road, and west of Plessis Road
5-4	Front of Winnipeg Mint corner #1 Highway and Lagimodiere Blvd.
5-5	Northeast corner of Lakewood Blvd. And Edgewater Drive
5-6	Clearwater Lake west of Beaverhill Blvd. And north of Edgewater Drive
5-7	Northwest corner of Lakewood Blvd. And Beaverhill Blvd. Still Water Lake
5-8	South of Edgewater Drive between Sweetwater Bay and Beaverhill Blvd. Sweetwater Lake
5-9	East of corner of Shamrock Drive and Newcroft Road
5-10	South of Willowlake crescent at Willow Point Road
5-11	North of Bishop Grandin Blvd. At Kearney Street
5-12	North of Bishop Grandin Blvd. At Glen Meadow Street
5-13	North of Bishop Grandin Blvd. At River Road
5-14	Between Mission Street and Dugald Road - West of Bournais Drive
5-15	South of Island Shore Blvd.
5-16	Southwest of Burland and Healy Crescent
5-17	Southeast of Burland and Westbourne Crescent
5-18	East of Dakota Street and south of John Forsythe Avenue
5-19	South of Island Lakes Drive
5-20	North of Island Lakes Drive and west of Blvd. De la Seigneurie
5-21	East and north of Royal Mint Drive
5-22	Southwest of Shorehill Drive and Aubin Drive
5-23	Northwest of St. Boniface Road and Murdock Road
6-1	Eve Werier Wildlife Pond - Assiniboine Forest
6-2	Northeast corner of Kenaston Blvd. and Grand Ave. Behind shopping centre
6-3	Southeast corner of Kenaston Blvd. And Grant Avenue
6-4	Lot 16 Drain west of Waverley
6-5	Lot 16 Drain east of Waverley

BASIN NUMBER	BASIN LOCATION
6-6	North of Chancellor between Swan Lake Bay and Lake Grove Bay
6-7	Along Lake Lindero Road Twin Lake
6-8	South of Markham Road at Forest Lake Drive Governor Lake
6-9	North of Markham Road west of Forest Lake Drive President Lake
6-10	North of Dalhousie Drive and east of Pembina Hwy. Baldry Creek Lake
6-11	South of Dalhousie Drive and east of Pembina Hwy. Baldry Creek Lake
6-12	North of Grandmont Boulevard and west of Molin Avenue
6-13	South of Grandmont Boulevard and west of Delorme Bay
6-14	Southwest of Whyteridge Blvd. And Henlow Bay
6-15	West of Shorecrest Drive
6-16	Point West Drive
6-17	Southwest Scurfield Boulevard and Columbia Drive
6-18	North of Shoreline Drive and south of Queens Park Crescent
6-19	South of West Taylor Drive and west of Dumbarton Blvd.
6-20	West of Scurfield Drive and north of Vanderbilt Drive
6-21	South of Belleiner Drive
6-22	North of Wilkes Avenue and west of Waverley Street

Stormwater Retention Basin Maps:

The following five pages identify the location of Stormwater Retention Basins (SRB's) within Winnipeg on maps of various city regions. SRB's within the city are identified according to a numbering scheme which relates to the former city administrative structure which utilized Operations Districts to undertake localized public works activities. Each basin is assigned two numbers separate by a hyphen. The first number indicates the former Operations District which the basin falls within. With the former Operations Districts now dissolved within the existing city structure, the first number remains a good indicator of the approximate region within the city which the SRB is located.

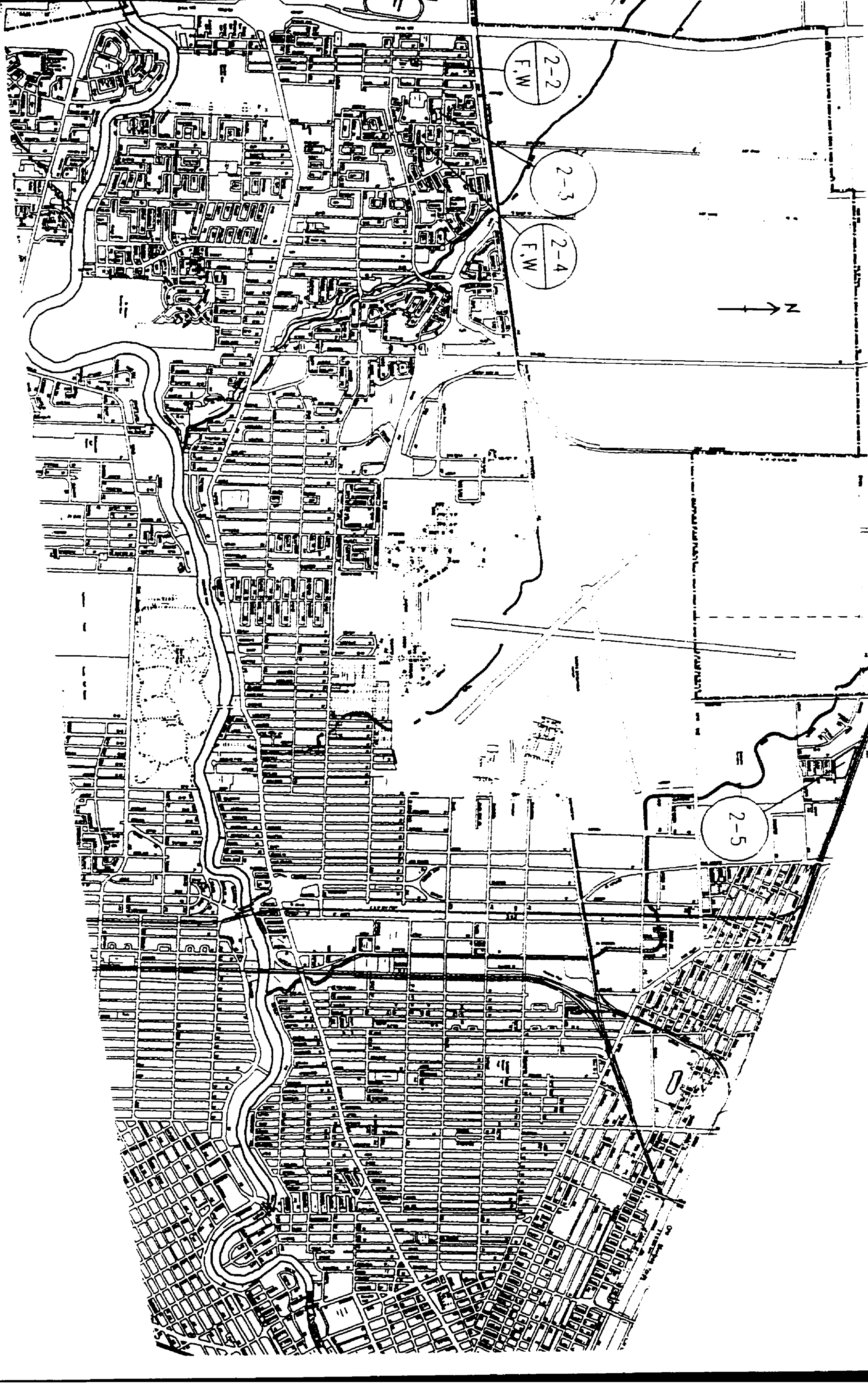
The second number is assigned sequentially to each SRB at the time the development, and therefore the SRB, is conceived. As such, the second number typically indicates the relative age of the basin within the former Operations District (ie. an older basin would typically have a lower second number and a newer basin would have a higher second number).

Each of the maps has a "North Arrow" inscribed upon it to assist the reader in orienting the map correctly. The SRB's on each map are identified by number, and some also have letter indicators marked. The letters indicate the following:

F = SRB has a Fountain on it.

P = SRB has a pumped discharge as opposed gravity drainage.

W = SRB has a well for flow augmentation during periods of low flow.



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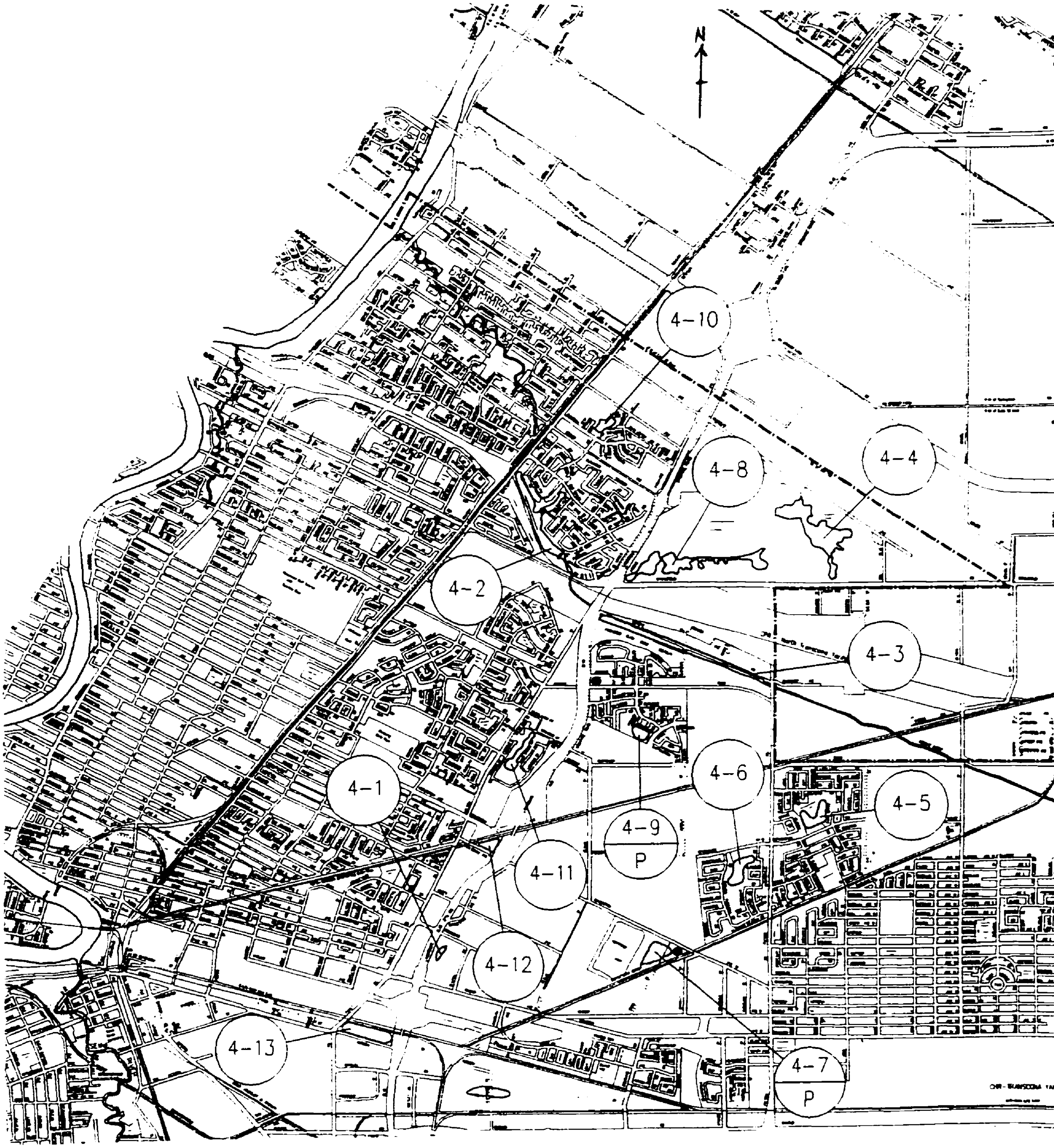
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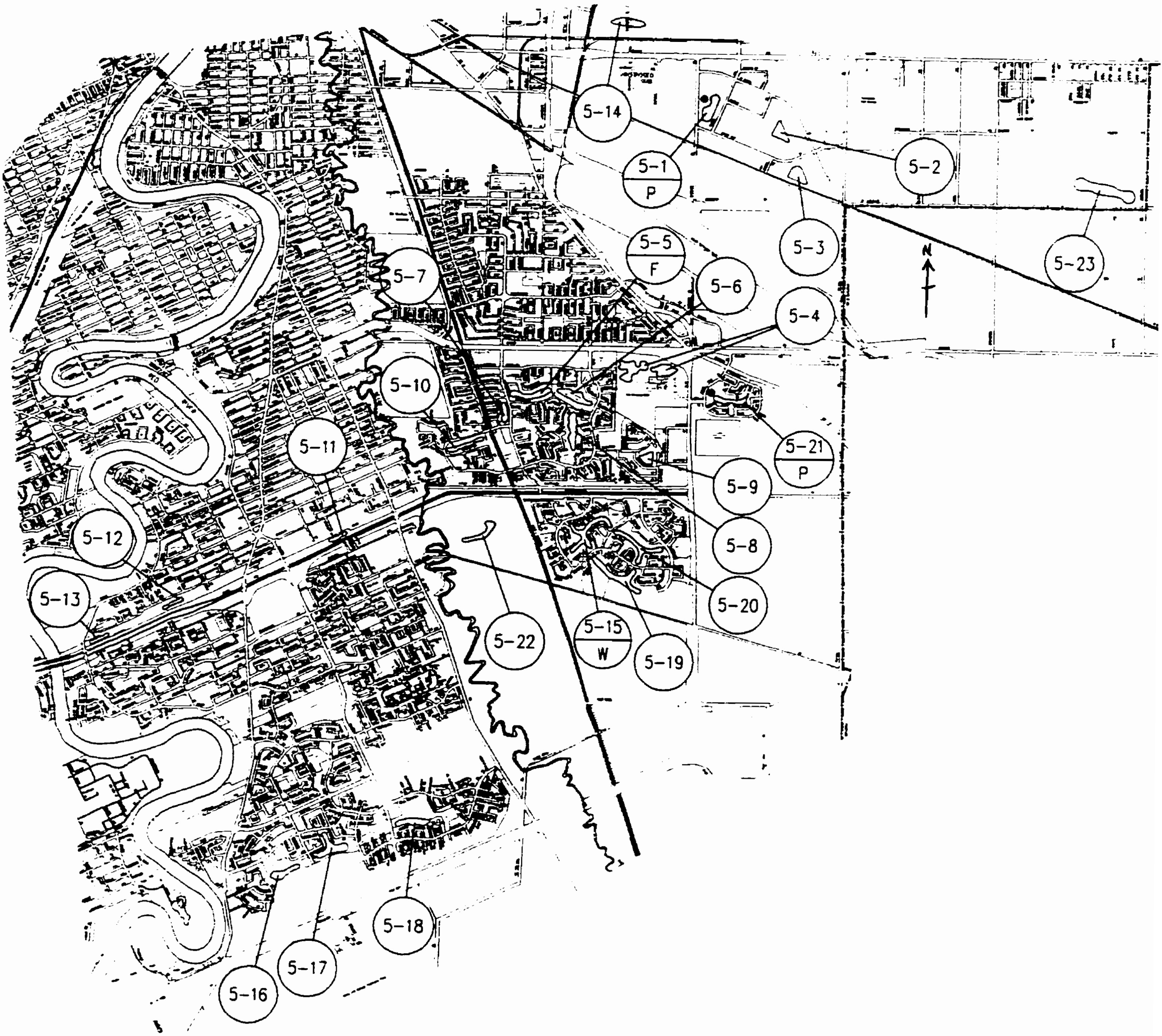
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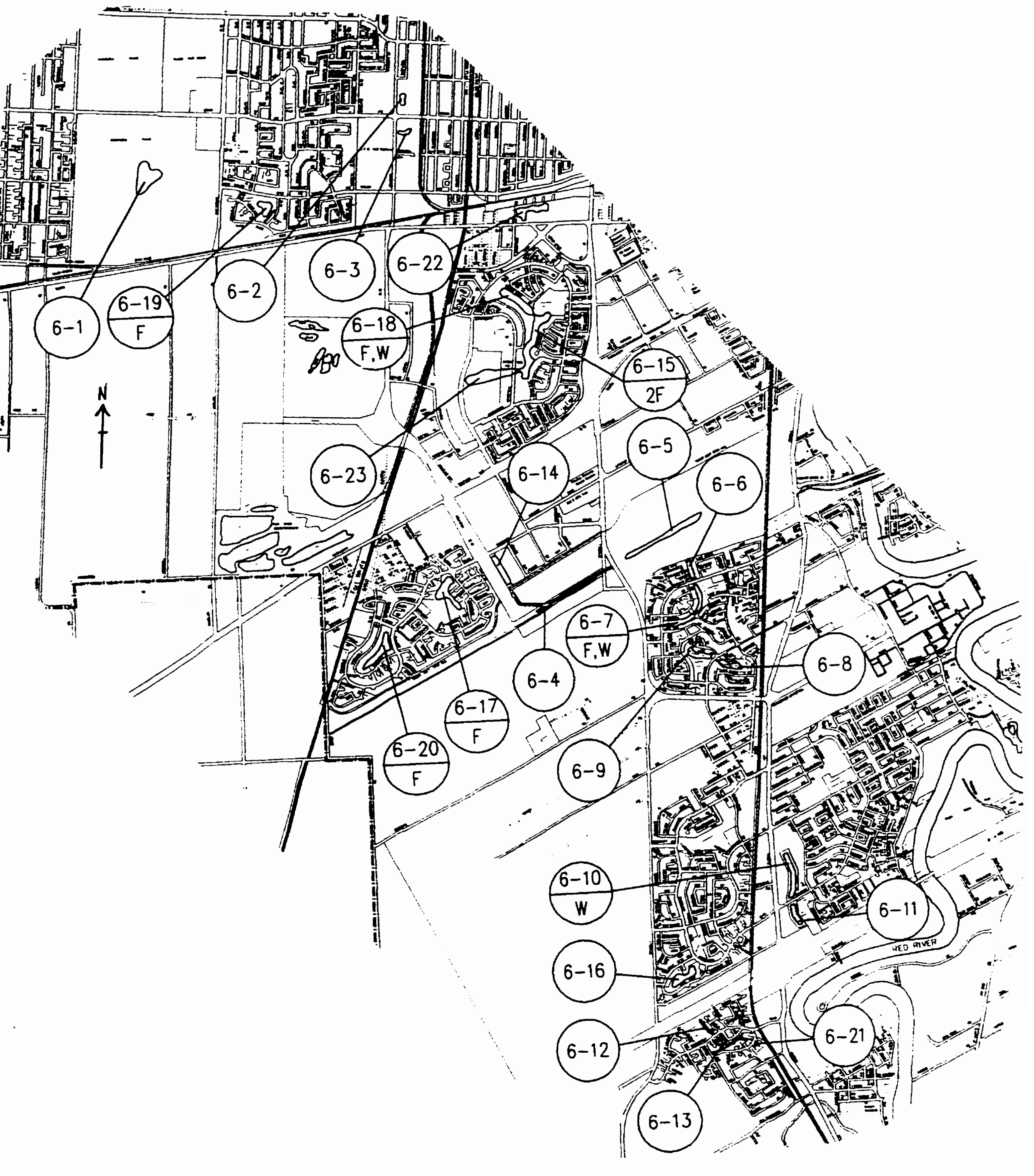
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3-7
3-8
3-9
W
3-10
W
3-11

APPENDIX III: 1995 & 1996 Stormwater Retention Basin Water Quality Analysis Raw Data

Table A-2 1995 Stormwater Retention Basin Water Quality Analysis Raw Data

Fort Richmond Drainage Network Baseline SRB's 6-10 & 6-11
St. Norbert Drainage Network Baseline SRB's 6-12 & 6-13
Harvested SRB's 3-2, 3-3 & 3-4

Chlorophyll a Analysis

Day #	SRB 6-10 Chlorophyll a (ug/L)	SRB 6-11 Chlorophyll a (ug/L)	Chlorophyll a Baseline value (ug/L) (Mean of SRB's 6-10 & 6-11)	SRB 6-12 Chlorophyll a (ug/L)	SRB 6-13 Chlorophyll a (ug/L)	Chlorophyll a Baseline value (ug/L) (Mean of SRB's 6-12 & 6-13)	SRB 3-2 Chlorophyll a (ug/L)	SRB 3-3 Chlorophyll a (ug/L)	SRB 3-4 Chlorophyll a (ug/L)
138	44	31	38	5	6	7	21	29	13
152	79	34	57	8	6	6	53	35	48
170	155	118	136	2	11	7	17	27	3
178	103	84	88	8	142	75	143	80	58
184	45	21	38	2	2	3	23	54	77
208	44	38	40	18	33	26	28	158	43
226	130	92	114	70	41	56	58	231	24
238	2	0	4	56	48	52	55	114	108

Turbidity Analysis

Day #	SRB 6-10 Turbidity (ntu)	SRB 6-11 Turbidity (ntu)	Turbidity Baseline value (ntu) (Mean of SRB's 6-10 & 6-11)	SRB 6-12 Turbidity (ntu)	SRB 6-13 Turbidity (ntu)	Turbidity Baseline value (ntu) (Mean of SRB's 6-12 & 6-13)	SRB 3-2 Turbidity (ntu)	SRB 3-3 Turbidity (ntu)	SRB 3-4 Turbidity (ntu)
138	6.6	6.6	7.7	2.8	3.6	3.1	4.1	3.8	24
170	1.8	1.7	8.8	1.8	1.6	1.7	2.0	3.3	2.4
184	8.8	1.2	10.4	1.2	3.6	2.4	4.3	8.3	8.8
226	29	1.4	21.5	9.6	6.3	7.7	4.3	11	3.2

Transparency Analysis

Day #	SRB 6-10 Transparency (m)	SRB 6-11 Transparency (m)	Transparency Baseline value (m) (Mean of SRB's 6-10 & 6-11)	SRB 6-12 Transparency (m)	SRB 6-13 Transparency (m)	Transparency Baseline value (m) (Mean of SRB's 6-12 & 6-13)	SRB 3-2 Transparency (m)	SRB 3-3 Transparency (m)	SRB 3-4 Transparency (m)
138	0.3	0.3	0.30	0.8	0.7	0.80	0.2	0.2	0.8
152	0.3	0.5	0.40	1.0	1.0	1.00	0.3	0.3	0.3
170	0.1	0.1	0.10	0.3	0.8	0.60	1.0	0.8	0.8
178	0.2	0.3	0.25	0.8	0.6	0.75	0.2	0.8	0.4
184	0.3	0.3	0.30	0.8	0.4	0.50	0.5	0.3	0.3
208	0.2	0.2	0.20	0.5	0.4	0.45	0.8	0.1	0.2
226	0.1	0.1	0.10	0.1	0.3	0.20	0.8	0.1	0.5
238	0.1	0.1	0.10	0.1	0.1	0.10	0.6	0.1	0.3

pH Analysis

Day #	SRB 6-10 pH	SRB 6-11 pH	pH Baseline value (Mean of SRB's 6-10 & 6-11)	SRB 6-12 pH	SRB 6-13 pH	pH Baseline value (Mean of SRB's 6-12 & 6-13)	SRB 3-2 pH	SRB 3-3 pH	SRB 3-4 pH
138	9.0	9.0	9.0	8.8	9.3	9.0	8.3	9.7	9.0
170	8.3	9.4	9.4	10.0	10.0	10.0	8.4	9.5	9.8
184	8.6	[illegible]	9.0	9.8	10.0	10.0	8.3	8.7	10.0
226	8.7	8.5	8.8	9.0	8.6	8.8	8.5	9.4	8.8

Table A-3 1996 Stormwater Retention Basin Water Quality Analysis Raw Data

Fort Richmond Drainage Network Baseline SRB's 6-10 & 6-11
St. Norbert Drainage Network Baseline SRB's 6-12 & 6-13
Harvested SRB's 6-7, 6-8 & 6-6
Harmex DF Test SRB's 2-4 (surface), 5-15 (perimeter), 5-18 (surface)
Regene A Test SRB's 4-10 (surface) & 5-21 (perimeter)

Chlorophyll a Analysis

Day #	SRB 6-10 Chlorophyll a (ug/L)	SRB 6-11 Chlorophyll a (ug/L)	Chlorophyll a Baseline value (ug/L) (Mean of SRB's 6-10 & 6-11)	SRB 6-12 Chlorophyll a (ug/L)	SRB 6-13 Chlorophyll a (ug/L)	Chlorophyll a Baseline value (ug/L) (Mean of SRB's 6-12 & 6-13)	SRB 6-7 Chlorophyll a (ug/L)	SRB 6-8 Chlorophyll a (ug/L)	SRB 6-6 Chlorophyll a (ug/L)	SRB 2-4 Chlorophyll a (ug/L)	SRB 5-15 Chlorophyll a (ug/L)	SRB 5-18 Chlorophyll a (ug/L)	SRB 4-10 Chlorophyll a (ug/L)	SRB 5-21 Chlorophyll a (ug/L)
154	22	17	20	20	24	22	2	3	2	6	12	20	23	8
168	22	31	27	14	11	13	14	2	13	3	46	11	15	16
183	58	36	47	18	21	18	32	2	38	4	58	12	44	28
198	114	64	89	104	31	66	61	20	114	3	30	18	38	38
210	55	59	57		3	7	67	61	35	3	22	24	51	35
233	45	53	50	7	5	13	153	116	154	4	45	27	31	14

Turbidity Analysis

Day #	SRB 6-10 Turbidity (ntu)	SRB 6-11 Turbidity (ntu)	Turbidity Baseline value (ntu) (Mean of SRB's 6-10 & 6-11)	SRB 6-12 Turbidity (ntu)	SRB 6-13 Turbidity (ntu)	Turbidity Baseline value (ntu) (Mean of SRB's 6-12 & 6-13)	SRB 6-7 Turbidity (ntu)	SRB 6-8 Turbidity (ntu)	SRB 6-6 Turbidity (ntu)	SRB 2-4 Turbidity (ntu)	SRB 5-15 Turbidity (ntu)	SRB 5-18 Turbidity (ntu)	SRB 4-10 Turbidity (ntu)	SRB 5-21 Turbidity (ntu)
154	12.5	17	14.8	7.6	8.2	7.9	7.6	3.5	2.8	1.1	4.7	8.0	5.6	2.3
183	14	6.6	12.0	6.3	10.0	8.2	6.5	1.8	11	0.80	18	2.1	13	2.8
210	8	26	22.0	3.3	2.8	3.1	6.3	27	7.0	1.1	11	4.1	15	3.3

Transparency Analysis

Day #	SRB 6-10 Transparency (m)	SRB 6-11 Transparency (m)	Transparency Baseline value (m) (Mean of SRB's 6-10 & 6-11)	SRB 6-12 Transparency (m)	SRB 6-13 Transparency (m)	Transparency Baseline value (m) (Mean of SRB's 6-12 & 6-13)	SRB 6-7 Transparency (m)	SRB 6-8 Transparency (m)	SRB 6-6 Transparency (m)	SRB 2-4 Transparency (m)	SRB 5-15 Transparency (m)	SRB 5-18 Transparency (m)	SRB 4-10 Transparency (m)	SRB 5-21 Transparency (m)
154	0.2	0.2	0.20	0.3	0.2	0.25	0.8	0.5	0.5	1.3	0.4	0.2	0.3	0.5
168	0.3	0.2	0.25	0.3	0.2	0.20	0.4	0.8	0.4	1.0	0.1	0.3	0.3	1.0
183	0.1	0.3	0.15	0.2	0.3	0.20	0.2	0.8	0.2	1.1	0.1	0.4	0.3	0.3
198	0.2	0.3	0.20	0.3	0.3	0.30	0.4	0.7	0.2	1.1	0.3	0.3	0.1	0.6
210	0.1	0.1	0.10	0.8	0.7	0.75	0.2	0.5	0.2	1.2	0.3	0.3	0.2	0.4
233	0.1	0.1	0.40	0.8	0.8	0.80	0.1	0.3	0.1	0.3	0.2	0.1	Not Meas.	Not Meas.

pH Analysis

Day #	SRB 6-10 pH	SRB 6-11 pH	pH Baseline value (Mean of SRB's 6-10 & 6-11)	SRB 6-12 pH	SRB 6-13 pH	pH Baseline value (Mean of SRB's 6-12 & 6-13)	SRB 6-7 pH	SRB 6-8 pH	SRB 6-6 pH	SRB 2-4 pH	SRB 5-15 pH	SRB 5-18 pH	SRB 4-10 pH	SRB 5-21 pH
154	8.8	8.8	8.8	7.8	7.7	7.7	8.4	8.6	8.7	8.1	8.2	8.8	8.2	9.4
183	8.4	8.2	8.3	8.6	8.3	8.2	10.4	10.8	11.0	8.5	8.8	9.2	8.5	10.4
210	8.7	8.8	8.8	8.5	8.7	8.6	8.3	8.8	8.7	8.3	8.5	8.3	8.3	10.5

TABLE A-4 1995 Stormwater Retention Basin Raw Nutrient Data

Fort Richmond Drainage Network Baseline SHB's 6-10 & 6-11
St. Norbert Drainage Network Baseline SHB's 6-12 & 6-13
Harvested SHB's 3-2, 3-3 & 3-4

Nitrate Nitrogen Analysis

Day #	SHB 6-10 Nitrate Nitrogen (mg/L)	SHB 6-11 Nitrate Nitrogen (mg/L)	Nitrate Nitrogen Baseline Value (mg/L) (Mean of SHB's 6-10 & 6-11)	SHB 6-12 Nitrate Nitrogen (mg/L)	SHB 6-13 Nitrate Nitrogen (mg/L)	Nitrate Nitrogen Baseline Value (mg/L) (Mean of SHB's 6-12 & 6-13)	SHB 3-2 Nitrate Nitrogen (mg/L)	SHB 3-3 Nitrate Nitrogen (mg/L)	SHB 3-4 Nitrate Nitrogen (mg/L)
138	0.04	0.04	0.04	0.04	[illegible]	0.04	[illegible]	[illegible]	[illegible]
170	0.04	0.04	0.04	1.60	1.60	1.58	[illegible]	[illegible]	[illegible]
184	[illegible]	0.04	0.04	[illegible]	[illegible]	0.04	[illegible]	[illegible]	[illegible]
226	[illegible]	[illegible]	0.04	[illegible]	[illegible]	0.04	[illegible]	[illegible]	[illegible]

Total Kjeldahl Nitrogen Analysis

Day #	SHB 6-10 TKN (mg/L)	SHB 6-11 TKN (mg/L)	TKN Baseline Value (mg/L) (Mean of SHB's 6-10 & 6-11)	SHB 6-12 TKN (mg/L)	SHB 6-13 TKN (mg/L)	TKN Baseline Value (mg/L) (Mean of SHB's 6-12 & 6-13)	SHB 3-2 TKN (mg/L)	SHB 3-3 TKN (mg/L)	SHB 3-4 TKN (mg/L)
138	1.76	1.67	1.72	2.16	1.46	1.81	1.44	1.43	1.47
170	2.64	2.44	2.50	3.64	3.66	3.65	1.41	1.83	1.18
184	1.18	1.04	1.11	1.08	1.08	1.08	1.81	1.87	2.28
226	2.26	1.66	2.12	2.62	2.62	2.57	2.37	2.46	2.62

Total Phosphorous Analysis

Day #	SHB 6-10 Total Phosphorous (mg/L)	SHB 6-11 Total Phosphorous (mg/L)	Total Phosphorous Baseline Value (mg/L) (Mean of SHB's 6-10 & 6-11)	SHB 6-12 Total Phosphorous (mg/L)	SHB 6-13 Total Phosphorous (mg/L)	Total Phosphorous Baseline Value (mg/L) (Mean of SHB's 6-12 & 6-13)	SHB 3-2 Total Phosphorous (mg/L)	SHB 3-3 Total Phosphorous (mg/L)	SHB 3-4 Total Phosphorous (mg/L)
138	0.16	0.17	0.17	0.13	0.06	0.11	0.10	0.14	[illegible]
170	0.23	0.18	0.21	0.24	0.24	0.24	[illegible]	[illegible]	[illegible]
184	0.06	[illegible]	0.06	[illegible]	[illegible]	0.08	[illegible]	[illegible]	[illegible]
226	0.29	[illegible]	0.26	0.33	0.26	0.30	[illegible]	[illegible]	[illegible]

Table A-5 1996 Stormwater Retention Basin Raw Nutrient Data

Fort Richmond Drainage Network Baseline SHB's 6-10 & 6-11
St. Norbert Drainage Network Baseline SHB's 6-12 & 6-13
Harvested SHB's 6-7, 6-8 & 6-6
Karmas DF Test SHB's 2-4 (surface), 5-15 (perimeter), 5-18 (surface)
Regune A Test SHB's 4-10 (surface) & 5-21 (perimeter)

Nitrate Nitrogen Analysis

Day #	SHB 6-10 Nitrate Nitrogen (mg/L)	SHB 6-11 Nitrate Nitrogen (mg/L)	Nitrate Nitrogen Baseline Value (mg/L) (Mean of SHB's 6-10 & 6-11)	SHB 6-12 Nitrate Nitrogen (mg/L)	SHB 6-13 Nitrate Nitrogen (mg/L)	Nitrate Nitrogen Baseline Value (mg/L) (Mean of SHB's 6-12 & 6-13)	SHB 6-7 Nitrate Nitrogen (mg/L)	SHB 6-8 Nitrate Nitrogen (mg/L)	SHB 6-6 Nitrate Nitrogen (mg/L)	SHB 2-4 Nitrate Nitrogen (mg/L)	SHB 5-15 Nitrate Nitrogen (mg/L)	SHB 5-18 Nitrate Nitrogen (mg/L)	SHB 4-10 Nitrate Nitrogen (mg/L)	SHB 5-21 Nitrate Nitrogen (mg/L)
154	0.04	0.07	0.06	0.04	0.04	0.04	0.04	0.37	0.04	0.34	0.52	Not Read	0.11	0.05
183	0.04	0.04	0.04	[illegible]	0.16	[illegible]	0.14	0.04	0.04	Not Read	[illegible]	0.04	0.14	0.04
210	0.07	0.08	0.07	0.04	0.04	0.04	0.04	0.04	0.04	0.11	[illegible]	[illegible]	[illegible]	0.04
233	0.25	0.26	[illegible]	[illegible]	0.04	[illegible]	0.04	0.04	0.04	[illegible]	[illegible]	0.05	[illegible]	[illegible]

Total Kjeldahl Nitrogen Analysis

Day #	SHB 6-10 TKN (mg/L)	SHB 6-11 TKN (mg/L)	TKN Baseline Value (mg/L) (Mean of SHB's 6-10 & 6-11)	SHB 6-12 TKN (mg/L)	SHB 6-13 TKN (mg/L)	TKN Baseline Value (mg/L) (Mean of SHB's 6-12 & 6-13)	SHB 6-7 TKN (mg/L)	SHB 6-8 TKN (mg/L)	SHB 6-6 TKN (mg/L)	SHB 2-4 TKN (mg/L)	SHB 5-15 TKN (mg/L)	SHB 5-18 TKN (mg/L)	SHB 4-10 TKN (mg/L)	SHB 5-21 TKN (mg/L)
154	1.04	1.06	1.07	1.20	1.08	1.13	0.75	0.70	0.41	0.80	0.85	Not Read	0.90	0.70
183	3.06	2.78	2.92	2.58	2.04	2.31	2.70	1.16	3.11	1.65	2.61	2.03	1.22	2.46
210	3.48	2.47	2.46	1.87	1.74	1.81	2.58	1.63	3.15	1.61	1.80	1.75	1.60	2.41
233	1.64	2.16	2.02	2.33	1.66	2.11	3.17	2.30	3.63	2.36	1.62	[illegible]	[illegible]	2.44

Total Phosphorous Analysis

Day #	SHB 6-10 Total Phosphorous (mg/L)	SHB 6-11 Total Phosphorous (mg/L)	Total Phosphorous Baseline Value (mg/L) (Mean of SHB's 6-10 & 6-11)	SHB 6-12 Total Phosphorous (mg/L)	SHB 6-13 Total Phosphorous (mg/L)	Total Phosphorous Baseline Value (mg/L) (Mean of SHB's 6-12 & 6-13)	SHB 6-7 Total Phosphorous (mg/L)	SHB 6-8 Total Phosphorous (mg/L)	SHB 6-6 Total Phosphorous (mg/L)	SHB 2-4 Total Phosphorous (mg/L)	SHB 5-15 Total Phosphorous (mg/L)	SHB 5-18 Total Phosphorous (mg/L)	SHB 4-10 Total Phosphorous (mg/L)	SHB 5-21 Total Phosphorous (mg/L)
154	0.06	0.04	0.05	0.13	0.13	0.11	0.07	0.08	0.11	0.05	0.23	Not Read	0.04	0.05
183	0.25	0.20	0.23	0.58	0.29	0.43	0.25	0.16	0.16	0.07	0.24	[illegible]	[illegible]	[illegible]
210	0.26	0.14	0.20	0.29	0.31	0.29	0.16	0.26	[illegible]	0.08	[illegible]	[illegible]	[illegible]	[illegible]
233	0.15	0.16	0.15	0.23	0.21	[illegible]	0.24	0.35	0.40	0.17	[illegible]	[illegible]	[illegible]	[illegible]

APPENDIX IV: Stormwater Retention Basin Herbicide Application Field Observations

Figure A-14: Shoreline Application of Reglone A

Figure A-15: Application of Reglone A from Water Surface

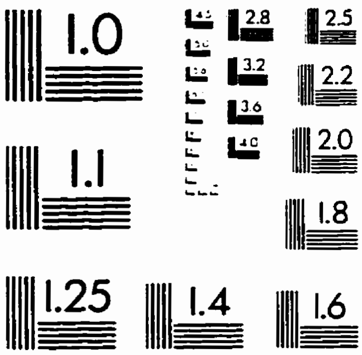
Figure A-16: SRB 2-4 Prior to 1997 Karmex DF Application (Looking East)

Figure A-17: SRB 2-4 Subsequent to 1997 Karmex DF Application (Looking East)

Figure A-18: SRB 2-4 Prior to 1997 Karmex DF Application (Looking West)

Figure A-19: SRB 2-4 Subsequent to 1997 Karmex DF Application (Looking West)

IMAGE EVALUATION TEST TARGET (QA-3)



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